The JOURNAL
OF THE
FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
DEVOTED TO SCIENCE AND THE MECHANIC ARTS

VOL. CLXXII JULY, 1911 No. 1

THE PRINCIPLE OF RELATIVITY.

BY

WM. S. FRANKLIN,
Lehigh University.

EVERY notion in physics which is independent of the minute and infinitely complicated particulars of varying points of view may be called an invariant.[1] Thus the kinetic energy[2] of a body is an invariant, the temperature of a body is an invariant, the mass of a body is an invariant, the volume of a body is an invariant, the electric charge on a body is an invariant, and so on. This does not mean that these various things are invariable, it only means that they are independent of the point of view. A gallon of water is a gallon of water from whatever point of view, and water at 100° C. is a definite thing from whatever point of view.

Perhaps the most widely accepted invariant ideas are those

[1] Consider the expression

$$(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2$$

in the Cartesian system of co-ordinates. This expression is equal to the square of the distance between two points, and the expression remains entirely unchanged in value however the axes of reference may be moved or turned. Similarly the differential expression for the square of the velocity of a body and the differential expression for the square of the acceleration of a body remain entirely unchanged when the axes of reference are moved or turned in any way. Such expressions are called *invariants*.

[2] Kinetic energy, temperature, mass and volume are not invariant if motion is purely relative as explained later.

[NOTE.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

Copyright, 1911, by THE FRANKLIN INSTITUTE.

which refer to time and space. The distance from New York to Philadelphia is 90 miles, and it is scarcely conceivable that a person could be placed in a condition which would force him to change his mind and think of the distance as 89 miles. Every person on the earth is able to say "Now, it is mean noon at Greenwich," and it is scarcely conceivable that a person could be placed in a condition which would make such a statement lose its meaning. It is scarcely conceivable how two persons using the same clock could be placed under conditions which would lead them to different results when they measure a given interval of time. And yet all these curious anomalies must exist, that is, time and length must depend upon the point of view of the observer, if motion is purely relative. It is the object of this paper to describe certain experiments which seem to show that motion is purely relative, not only in a limited mechanical sense, but in any and every sense, and to explain why the above mentioned anomalies (and others equally curious) must exist if motion is purely relative.

A man draws a weight towards his breast, but, of course, the exertion required differs greatly according as the man lies with his face downwards (in which case he draws the weight upwards), or with his face upwards (in which case he draws the weight downwards), or whether he stands erect (in which case he moves the weight horizontally). The effort required to move the weight over a given distance is not invariant with respect to change of direction in space. The recognition of the force of gravity, however, gives to us earth dwellers a system of mechanics which is invariant with respect to change of direction in space. Thus, the effect produced on a body by a force is independent of the direction of the force, due allowance being made for the force of gravity. What is here stated would perhaps completely satisfy a dweller on a flat earth, but the mere recognition of the force of gravity is not sufficient to give to us dwellers on a spherical earth a system of mechanics which is completely invariant with respect to changing directions in space. Let any one consider what he thought when he was first told of the people who walk around on the other side of the world with their feet up against the ground and their heads hanging downwards towards the sky! Indeed the introduction of the Copernican system into astronomy represents perhaps the greatest step that has ever been made towards the formation

of fundamental ideas of mechanical phenomena, ideas which are invariant with respect to varying points of view.

Every one appreciates the invariance of mechanical phenomena with respect to change of direction of the axes of reference as exemplified in the above discussion. Also every one has a fund of experience showing that mechanical phenomena are invariant with respect to uniform velocity through space. Thus the effect of the high velocity of the earth through space is insensible to us earth dwellers, and every one knows that the motion of a boat, if it is uniform, is imperceptible to a person in the boat if he does not look at some body outside the boat. Indeed it is generally conceded that uniform motion of a system cannot be detected by observations taken within the system by an observer who moves along with the system. The only way to perceive uniform velocity of a system is by reference to an outside system. That is to say, velocity is purely relative.

The postulate that velocity is purely relative is called the *principle of relativity*. This principle has been fully recognized in mechanics since the time of Huyghens, but it has not been hitherto recognized as applying to the phenomena of electricity and magnetism.

DOES THE PRINCIPLE OF RELATIVITY APPLY TO ELECTROMAGNETIC PHENOMENA?

Do the observable effects which are associated with electric charges, electric currents, and magnets depend upon the velocity of the system in which the effects take place, or does the principle of relativity apply to electromagnetic phenomena? In attempting to discuss this question one faces a very serious difficulty. Many of the phenomena of electricity and magnetism are not at all familiar. Indeed the one electromagnetic phenomenon which is familiar, the transmission of light, stands in most men's minds as an isolated fact, a fact which is not connected with any other observable effect whatever; and to say that light travels at a speed of 186,000 miles per second is to say that light transmission is not only beyond our native physical sense, but also beyond the reach of any but the most extraordinarily powerful physical imagination. To talk about the physical aspects of light transmission is to talk without sense to those who have had no experience in refined electromagnetic measurements, and it is to talk utterly without logical effect to those who have no

ideas as to the electromagnetic character of light. There is no help in the face of such a difficulty but to assert the electromagnetic character of light as a fact which is as well understood as anything in physics, and to state that Maxwell's theory —as the almost completely consistent group of informing ideas in electromagnetism is called—has, with all leading physicists, acquired a force sufficiently compelling to turn them away from the classical ideas of mechanics, and make them give up the thousand-year-old ideas of time and space. A remarkable fate indeed of a theory which during the lifetime of its author no one understood!

There is indeed definite experimental evidence in favor of the extension of the principle of relativity to include electromagnetic phenomena as well as mechanical phenomena, and a necessary consequence of this extension of the principle of relativity is an apparent perversion of our accepted ideas of space and time. We are forced to admit that it is not everywhere *now*,[3] and that *to-day* with us here is elsewhere *yesterday* or *to-morrow!* Surely a group of ideas which would force us to such a conclusion with increase of intelligence and unimpeached sense is worth talking about even if the details of Maxwell's theory be left out of the discussion.

SOME ELECTROMAGNETIC EFFECTS DEPENDENT ON MOTION.

A moving magnet exerts a propelling force on electric charge. This is exemplified in the ordinary dynamo in which a moving magnet causes an electric current to flow in a wire.

A moving electric charge exerts a force on a magnet. This is exemplified by the action of an electric wire on a compass needle. The moving charge in the wire (the electric current) exerts a force on the compass needle.

The above effects depend upon relative motion of two things, but the following effect is to be expected when two electric charges move along side by side. A moving charge is equivalent to an electric current. Therefore, two like charges, QQ, Fig. 1, moving along side by side are equivalent to two parallel currents in the same direction, and two such currents attract each other. Therefore the electrostatic repulsion of two like charges would be to some extent annulled by this current-attraction when the

[3] Differences in local time as reckoned at different places on the earth are, of course, not here referred to.

charges move along side by side. If the principle of relativity applies to electromagnetic phenomena, however, it would be necessarily impossible for an observer moving along with the two charges in Fig. 1 to detect any change in their repulsion.

No attempts have been made to detect the decreased repulsion of charges moving along side by side; the possible precision of force measurement is not great enough to make such an attempt worth while even though the experiments be arranged to make use of the very high velocity of the earth in its orbit.

FIG. 1.

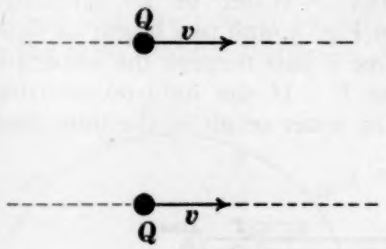
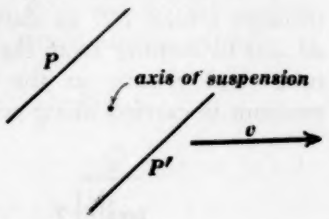


FIG. 2.



An electromagnetic effect in a moving system which is very closely related to the above and which would be easier to detect is as follows: Two insulated metal plates P P', Fig. 2, are suspended by a quartz fibre. When the system travels at velocity v one would expect that the charging of the two plates P and P' would give the suspended system a rotational impulse. Experiments made by Trouton and Noble in 1904, show, however, that this effect is non-existent, as one would expect from the principle of relativity.

THE PRINCIPLE OF RELATIVITY AND THE TRANSMISSION OF LIGHT.

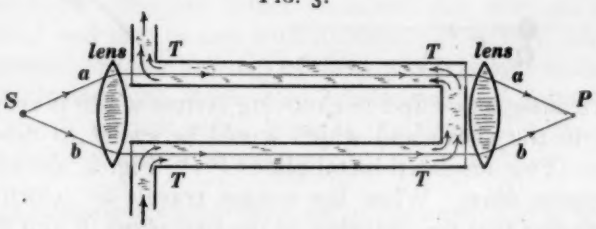
Certain well-known phenomena of light transmission depend upon the relative motion of two bodies. Thus the motion of the earth in its orbit causes an apparent motion of the fixed stars (astronomical aberration). The motion of a star towards the earth (or the motion of the earth towards a star) causes the lines in the star's spectrum to be shifted towards the violet (the Doppler effect).

Light has long been supposed to be a wave motion in a medium called the *ether*. If this is true then light must be thought of as having a definite velocity with respect to the ether of space just as sound has a definite velocity with respect to the

air through which it travels. Therefore the velocity of light relative to an observer on the moving earth would be less in the direction of the earth's orbital motion than in the opposite direction; and an observer on the earth by determining the velocity of light in different directions could detect the motion of the earth. Such a result would be contrary to the principle of relativity and there are two related experiments which show that the apparent velocity of light does not vary with the velocity of the observer, namely the "experiment of Fizeau" and the "experiment of Michelson and Morley."

THE EXPERIMENT OF FIZEAU.—Water or air circulates through a tube *TT*, as shown in Fig. 3, and two beams of light *aa* and *bb* coming from the source *S* pass through the respective tubes and reunite at the point *P*. If the light-transmitting medium is carried along with the water or air in the tube, then

FIG. 3.



the velocity of the beam *aa* with reference to the stationary parts of the apparatus would be $c-v$, and the velocity of the beam *bb* would be $c+v$, where c is the velocity of light in a stationary substance and v is the velocity of the fluid in the tubes *TT*. This difference in velocity would produce a certain retardation of the beam *aa* as compared with the beam *bb*, characteristic interference would be produced at the point *P*, and the relative retardation of the beam *aa* could be calculated from the observed character of the interference. Fizeau's experiment shows, however, that the light-transmitting ether is not [4] carried along with the fluid in the tube *TT*.

MICHELSON AND MORLEY'S EXPERIMENT.—Consider a light flash at the point *O*, Fig. 4, and let the circle *www* represent the position of the light wave after one second. The radius c of

[4] This statement is not quite complete. A full discussion of the experiments of Fizeau and Michelson and Morley is not here attempted. See Planck's *Acht Vorlesungen über theoretische Physik*, pages 111–116, 1910.

the circle represents the velocity of light with reference to the stationary point O. Consider the point P which was at O at the instant of the flash but which moves to the right at velocity v so that after one second OP' equals v. The velocity of the light wave ww with reference to the moving point P is $c - v$ in the forward direction (to the right in Fig. 4), $c + v$ in the backward direction (to the left in Fig. 4), and $\sqrt{c^2 - v^2}$ in a direction at right angles to v (upwards or downwards in Fig. 4).

Now a device for comparing the velocity of light (in a laboratory) in a direction parallel to the earth's orbital motion ($c \pm v$) with the velocity of light in a direction at right angles to the earth's orbital motion ($\sqrt{c^2 - v^2}$) would enable an observer

FIG. 4.

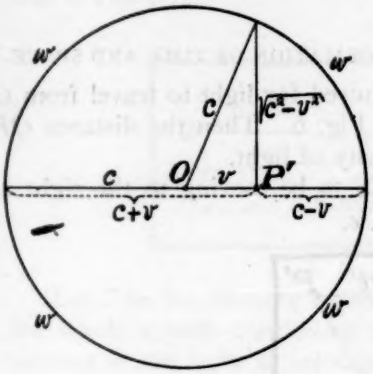
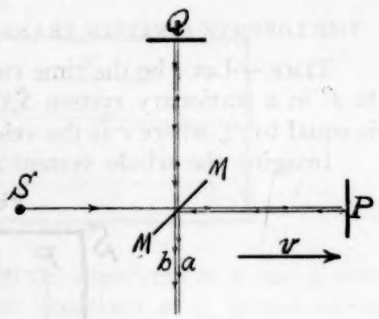


FIG. 5.



to detect the orbital motion of the earth in his laboratory, and indeed the comparison may be made *in* the laboratory because Fizeau's experiment shows that the ether is not carried along in a moving substance (laboratory walls and surrounding atmosphere).

The arrangement used by Michelson and Morley for comparing the two velocities $c \pm v$ and $\sqrt{c^2 - v^2}$ is shown in Fig. 5. Light from the source S strikes a semi-reflecting mirror MM. Part of the incident light goes through MM, travels to the distant mirror P and back again and is then partly reflected downwards by the mirror MM as the ray a. The remainder of the incident light is reflected by MM, and after travelling to the mirror Q and back again it is partly transmitted by the mirror MM as ray b. If a longer time is required for the ray a to

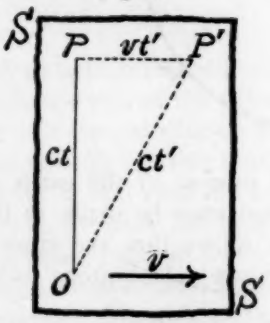
travel from O to P and back again than for the ray b to travel from O to Q and back again, then the two rays a and b will show characteristic interference, from which the difference of the velocities of light in the two directions can be calculated; but Michelson and Morley's results show that the influence of the observer's motion on the apparent velocity of light (see Fig. 4) is illusory, such an effect does not exist. In other words it takes light the same length of time to go from O to P and back again, as from O to Q, and back again (see Fig. 5) in spite of the orbital velocity, v, of the earth. All of this is in accord with the principle of relativity, and in the following section the invariance of the velocity of light (its independence of the velocity of the system in which it is measured) is used as a basis for the discussion of the remarkable Lorentz-Einstein transformation of time and space.

THE LORENTZ-EINSTEIN TRANSFORMATION OF TIME AND SPACE.

TIME.—Let t be the time required for light to travel from O to P in a stationary system SS, Fig. 6. Then the distance OP is equal to ct, where c is the velocity of light.

Imagine the whole system SS to be moving to the right at

Fig. 6.



velocity v. Then light, in travelling from a moving observer at O to a moving observer at P, really travels from O to P'. Let t' be the time required for light to travel thus from O to P'. Then the distance OP' is equal to ct', the distance PP' is equal to vt', and from the right triangle OPP' we have

$$c^2t'^2 = v^2t'^2 + c^2t^2$$

or $$(c^2 - v^2)t'^2 = c^2t^2$$

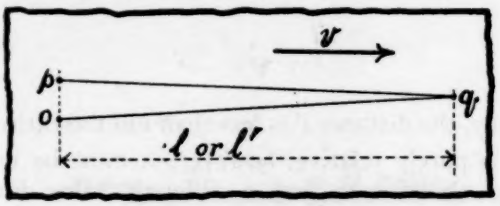
or $$\frac{t}{t'} = \frac{\sqrt{c^2 - v^2}}{c}$$

But if motion is purely relative, it must be impossible for an observer moving with the system to perceive that the time t' is greater than the time t. That is to say, a moving observer would measure the greater time t' and find it the same in value as the stationary observer finds the lesser time t, and therefore the unit of time of the moving observer must be greater than the unit of time of the stationary observer in the ratio of

$$c : \sqrt{c^2 - v^2}.$$

SPACE.—Let l be the distance pq or qo in Fig. 7 when the system is standing still. Then the time, t, required for light to travel from a stationary observer at p to a stationary observer at q and back again to o is equal to the distance $2l$ divided by c, that is $t = 2l/c$.

FIG. 7.



Let l' be the distance between the observers at p and q when the whole system (including the observers at p, q and o) are moving to the right at velocity v. Then the velocity of light to the right (relative to the moving observers) is $c - v$, and the time required for light to travel from p to q is $\frac{l'}{c-v}$; furthermore the velocity of light to the left (relative to the moving observers) is $c + v$, and the time required for light to travel from q to o is $\frac{l'}{c+v}$. Therefore the time, t' required for light to travel from p to q and back to o is

$$t' = \frac{l'}{c-v} + \frac{l'}{c+v}$$

and by a simple algebraic transformation this gives

$$t' = \frac{2l'}{c} \cdot \frac{c^2}{c^2 - v^2} \qquad \text{(a)}$$

Now if motion is purely relative, the time t' as measured by the moving observers must be equal in *value* to $t\left(=\frac{2l}{c}\right)$ as measured by the stationary observers, but the time unit of the moving observers is greater than the time unit of the stationary observers in the ratio $c:\sqrt{c^2-v^2}$. Therefore t', expressed in the time unit of the stationary observers is equal to

$$\frac{c}{\sqrt{c^2-v^2}}\times t,$$

or to

$$\frac{c}{\sqrt{c^2-v^2}}\times\frac{2l}{c}.$$

Placing this value of t' into equation (a) and reducing we have

$$\frac{l}{l'}=\frac{c}{\sqrt{c^2-v^2}}.$$

That is to say, the distance l' is less than l in the ratio $\sqrt{c^2-v^2}:c$. If motion is purely relative, however, it must be impossble for the moving observer to find a different value for l' than is found by the stationary observer for l. And therefore, the yard-stick in a moving system (when it is parallel to the velocity of the system) is shorter than it is in the stationary system in the ratio $\sqrt{c^2-v^2}:c$.

This difference of time and space measurement in two systems, one of which moves with respect to the other, was discovered partly by Lorentz and partly by Einstein and it is called the Lorentz-Einstein transformation.[5]

Consider a stationary observer A and another observer B who is moving to the right at velocity v. In describing the space and time relations of A and B it is convenient in speakng of measurements to right or left as made by A as constituting

[5] A good and simple mathematical discussion of this transformation is given by Planck in his *Acht Vorlesungen über theoretische Physik*, pages 118–122, Leipsig, 1910. These lectures were delivered at Columbia University in 1909.

"A's space," and of measurements to right or left as made by B as constituting "B's space." It is also convenient to speak of time "as reckoned by A" and of time "as reckoned by B." Space and time as measured and reckoned by A are represented by x and t, and space and time as reckoned by B are represented by x' and t'.

A complete picture of the Lorentz-Einstein transformation of

FIG. 8.

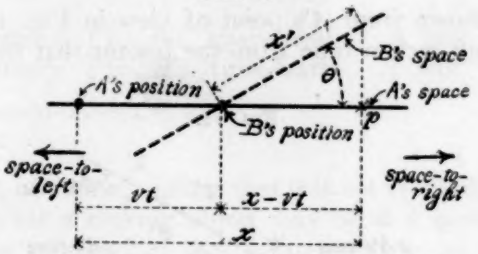
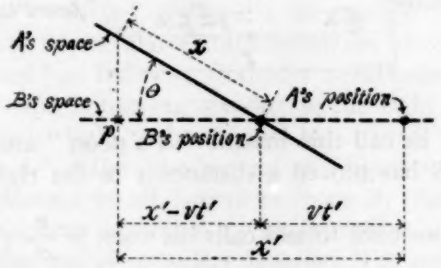


FIG. 9.

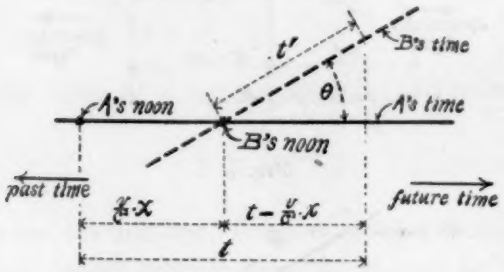


space is shown in Figs. 8 and 9. Let us consider especially Fig. 8 which shows B travelling to the right through A's space. The distance from A to any point p, as measured by A, is x; the distance from A to B, as measured by A, is vt, and the distance from B to p, as measured by B, is x'. The construction angle θ * is an angle whose cosine is $\sqrt{c^2-v^2}/c$.

* Minkowski has shown that this angle θ is an angle of rotation of all space (x, y and z) about the plane yz in a fourth dimension. See *Physikalische Zeitschrift* 10, pages 104–111, February, 1909.

Observer B travels to the right through A's space at a velocity of v centimetres per second. This, of course, everyone understands; but the remarkable thing about the Lorentz-Einstein transformation (the necessity of which is explained in connection with Figs. 11, 12 and 13) is that we are forced to conclude that B also moves through A's time towards the future at the rate of $\frac{v}{c^2}$ seconds per centimetre. This transformation of time is shown from A's point of view in Fig. 10. Suppose A and B both reckon time from the instant that they pass each

FIG. 10.



other, and let us call this instant "A's noon" and "B's noon." Then, when B has moved a distance x to the right, the instant which B reckons back to and calls his noon is $\frac{v}{c^2} \cdot x$ seconds after noon to A, and the instant which A reckons back to and calls his noon is Bq seconds before noon to B. Indeed x need not be a distance travelled by B; consider a place x centimetres to the right (or left) of A, it is $\frac{v}{c^2} \cdot x$ seconds after noon (or before noon) to A when it is noon *at that place* to B. When it is everywhere "now" to A it is not everywhere "now" to B; that is two events which are simultaneous to A are not simultaneous to B if they are at different places.

PARALLEL STATEMENTS REFERRING TO FIGS. 8 AND 10.

$$\left\{\begin{array}{l}\text{At a } \textit{time} \quad t \textit{ seconds} \quad \textit{later-than} \quad A\text{'s } \textit{noon} \\ \text{At a } \textit{place} \quad x \textit{ centimetres} \quad \textit{to-the-right-of} \quad A\text{'s } \textit{position}\end{array}\right.$$

$$\left\{\begin{array}{l}\text{in Fig. 8, } B \text{ has penetrated} \\ \text{in Fig. 10, } B \text{ has}^{7} \text{ penetrated}\end{array}\right. \quad \left\{\begin{array}{ll} vt & \textit{centimetres} \\ \frac{v}{c^2} \cdot x & \textit{seconds}\end{array}\right. \quad \text{into } A\text{'s}$$

$$\left\{\begin{array}{l}\textit{space-to-the-right,} \\ \textit{future,}\end{array}\right.$$

$$\text{or with reference } \left\{\begin{array}{l}\text{to } B\text{'s space-frame, } A \text{ has penetrated} \\ \text{to } B\text{'s time-frame, } A \text{ has}^{7} \text{ penetrated}\end{array}\right. \quad \left\{\begin{array}{l}\text{into } B\text{'s } \textit{space-to-the-left.} \\ \text{into } B\text{'s } \textit{past.}\end{array}\right.$$

Everyone, of course, realizes that it is not everywhere "here," and however far a moving object may be at a given instant it will be "here" "then" if *then* is late enough; so, in the new conception of time, it is not everywhere "now" but however early or late it may be at a given place in a moving system it will be[7] "now" "there" if *there* is far enough.[8]

The necessity of the above transformation of space and time may be explained[9] as follows: Consider a stationary observer A and another B who is moving steadily to the right at velocity v. Imagine a flash of light to be emitted by A or B at the instant that B passes A. After one second the light wave will have travelled a distance c in all directions from A, that is, the light wave will be a sphere of radius c with its centre at A, as shown in Fig. 11. Observer A considers observer B as not at the centre

---

[7] There is no form of a verb which can be properly used here. Referring to Fig. 8 the form *has penetrated* is proper, but referring to Fig. 10 a form should be used which is related to space exactly as ordinary past tense is related to time. Thus in Fig. 8, B has moved vt centimetres to the right during the time t, whereas in Fig. 10 we may say that B "has moved" $\frac{v}{c^2} \times x$ seconds into A's future; but no time has elapsed, only space x "has been" put behind.

[8] The similarity of space and time has been completely formulated by Minkowski in a paper that is rather difficult to read. See *Physikalische Zeitschrift*, February, 1909.

[9] The following discussion is not complete. See Planck's *Acht Vorlesungen*, pages 118–122.

of this sphere because during the one second of time B has moved a distance v to the right (to B) as shown. If motion is purely relative, however, observer B would be justified in considering himself to be stationary and A as moving to the left at velocity v, and therefore, from B's point of view, the light wave must be a sphere of radius c with its centre at B, and of course, B would consider that A is not at the centre of this sphere.

If motion is purely relative, these two points of view (of observer A and of observer B) are equally correct; A waits one second after the light flash and measures out to the light wave finding it to be a sphere of radius c with himself at the centre. In the same way, B waits one second after the light flash and measures out to the light wave and he also finds the wave to be a sphere of radius c but with himself at its centre. It seems as though A and B must be in hopeless disagreement as to where the light wave is after one second. The only escape from this dilemma is to admit that the two observers differ from each other as follows:

1. They do not reckon the passage of time in the same way.
2. Events which are considered to be simultaneous by A are not simultaneous to B, and *vice versa*.
3. They do not measure space in the same way, and
4. They do not measure time in the same way.

Observer A, who thinks he is at rest, sees B's measuring stick shortened (when it is parallel to B's direction of motion), and B, who thinks he is at rest, sees A's measuring stick shortened (when it is parallel to the direction of A's motion).

Fig. 11 represents the light wave in A's space after one second as reckoned by A, and Fig. 12 shows the light wave in B's space after one second as reckoned by B. The circle in Fig. 13 shows the light wave in A's space after the lapse of 1.154 seconds as reckoned by A, and the ellipse shows the light wave as measured by A when *at each point of the wave* it is one second after B's noon as reckoned by B. The ellipse is, of course, in A's space inasmuch as it is measured by A; but as seen by B the ellipse is shortened in the direction of the motion of A with respect to B, and it becomes a circle as shown in Fig. 12, with B at its centre.

Our experience has not supplied us with a ready-made sense-

frame, or aperceptive complex, or intuition or what-you-may-call-it whereby we can see things in the unusual way represented by the Lorentz-Einstein transformation. Indeed, taking *A*'s point of view we can understand *B*'s point of view as a

FIG. 11.

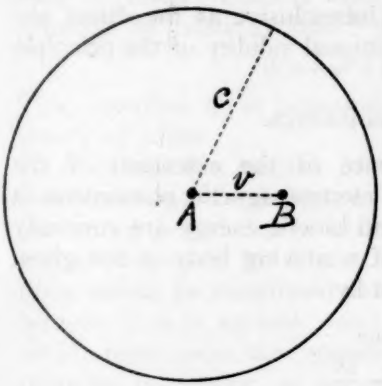


FIG. 12.

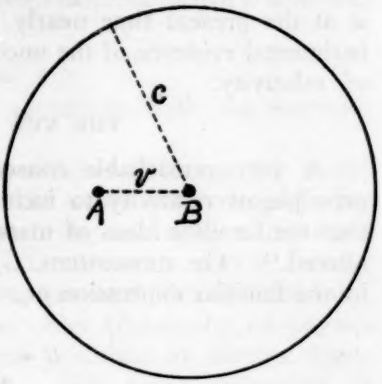
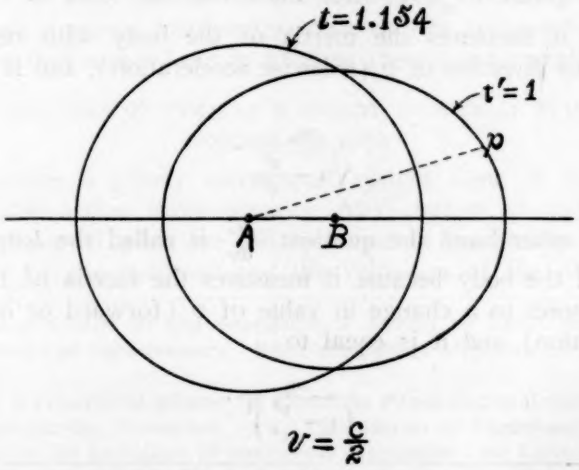


FIG. 13.



$v = \frac{c}{2}$

delusion but not otherwise, although *B*'s point of view is as legitimate as our own (*A*'s) and we would accept it as our own if we were in *B*'s place and then we would consider *A*'s point of view as a delusion. Perhaps *A* may sometime discuss

the matter with B and settle the question. Well, it is pretty nearly settled already by the experiment of Trouton and Noble and by the interferometer experiment of Michelson and Morley, to say nothing of such indirect evidence as the light-pressure experiment of Nichols and Hull.[10] Indeed the direct experimental evidence of the principle of the conservation of energy is at the present time nearly as inconclusive as the direct experimental evidence of the unconditional validity of the principle of relativity.

THE NEW MECHANICS.

A very remarkable consequence of the extension of the principle of relativity to include electromagnetic phenomena is that the familiar ideas of mass and kinetic energy are curiously altered.[11] The momentum, G, of a moving body is not given by the familiar expression $m_0 v$ but by

$$G = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

The quotient $\frac{G}{v}$ is called the *transverse mass* of the body because it measures the inertia of the body with respect to change of direction of v (sidewise acceleration), and it is equal to

$$\frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

On the other hand the quotient $\frac{dG}{dv}$ is called the *longitudinal mass* of the body because it measures the inertia of the body with respect to a change in value of v (forward or backward acceleration) and it is equal to

$$\frac{m_0}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{3}{2}}}.$$

---

[10] See a very simple paper by G. N. Lewis, *Philosophical Magazine*, vol. 16, pages 705–716, November, 1908.

[11] The simplest discussion of this subject is given by G. N. Lewis, *Philosophical Magazine*, vol. 16, pages 705–717, November, 1908, and by Lewis and Tolman, *Philosophical Magazine*, vol. 18, pages 510–523, October, 1909.

In general therefore the mass of a body depends on its velocity, and the above expressions have been quite accurately verified by experiments of Bucherer and of Hupka on the magnetic deflection of moving electrons.

The familiar expression for the kinetic energy of a moving body is $\frac{1}{2}m_0v^2$ whereas the electromagnetic theory and the principle of relativity lead [12] to

$$W = m_0c^2 + \tfrac{1}{2}m_0v^2 + \cdots$$

This equation is in substantial agreement with the electron-theory of mass.

It is not the purpose of this article to discuss the recent theories of mass and energy, and the above very meagre statements are introduced in order to bring out a very important matter discussed by Planck.[13] If motion is purely relative mass cannot be considered as a fundamental idea in mechanics, because it is a variant; and the older philosophy of physics which rests upon the fundamental postulate of definite mass-particles in motion is untenable. This older philosophy of physics attempted to reduce every phenomenon to a "mode of motion" in the familiar mechanical sense of this term, and if motion is purely relative this reduction is impossible because the thing that moves loses its identity (becomes a variant).

IS THE IDEA OF TIME AS A STEADY UNIVERSAL FLUX A LEGITIMATE IDEA?

Consider a purely mechanical system (one in which no irreversible action takes place). Any change of this system after a lapse of what we call time can be completely specified in terms of the positions and the velocities of the component

[12] The first term of this expression is derived by Lewis from simple considerations of light pressure. See *Philosophical Magazine*, vol. 16, pages 706–708.

[13] See a remarkable address by Planck in *Physikalische Zeitschrift*, 11th year, pages 922–932, November, 1910. This address of Planck and Larmor's discussion of the limitations of mechanical explanation (see Larmor's *Æther and Matter*, Appendix B, Cambridge University Press, 1909) are the most complete statements hitherto made concerning the significance of the classical mechanics. The classical mechanics is limited in another direction by thermodynamics as explained in a very simple way by the present writer in an article entitled "The Second Law of Thermodynamics; Its Basis in Intuition and Common Sense"; see *Popular Science Monthly*, March, 1910.

parts of the system without any reference whatever to the time which has elapsed since the beginning. Therefore, to say that time has elapsed is to introduce an arbitrary and meaningless difference between the initial and final states of the system in addition to the differences already completely specified in mechanical terms. It seems, of course, absurd to make this statement because every one realizes in looking at the ideal mechanical system that time has elapsed between its initial state and final state; but this view of the matter involves the inclusion in our ideal system of one's own physical body and the projection of one's own consciousness into the aggregate of phenomena under consideration. Let us, therefore, consider our ideal system apart from its relation to any outside condition whatever. Then, to say that time has elapsed is to introduce an arbitrary and meaningless difference between the initial and final state of the system.

Consider a system in which irreversible processes take place. Such a system departs farther and farther from its initial condition without possibility of return, but in this case a complete specification of the change in the system can be made in terms of mechanical specifications and entropy specifications, and it would seem to be meaningless to add a further specification of lapse of time to what is otherwise complete.

What we call time, when reduced to its simplest terms, is a phenomenon of consciousness, and our sense of the inevitable forward movement of time is dependent upon the existence of irreversible processes everywhere about us and especially inside of us. That is to say, our sense of the forward movement of time and the law of increase of entropy are based upon or grow out of the same fundamental condition of nature. It would seem, therefore, that the universal steady flux of time is an idea, not a physical fact, although, taking the universe as a whole, local irregularities become individually negligible and the entire process of nature may be thought of as one vast steady sweep in which increase of entropy and passage of time, much as they differ in our local methods of measuring them, refer fundamentally to the same thing.

The extent to which the idea of the steady flux of time prevades our habitual modes of thought is the outgrowth of

the methods we have come to use in the expression of our rather complicated experiences relating to what we call coincidences in time. Indeed some of the most pervasive things of the human mind are ideations which have been developed in connection with language, and to make due allowance for them in a physical discussion is sometimes very difficult indeed, partly because we fail to recognize the ideations as such and partly because we are left without adequate forms of expression if we set them aside. We always make time specifications with respect to a recurrent phenomenon like the rising of the sun, with finer gradations based upon the oscillation of a pendulum; our time specifications are simple counts of these recurrent phenomena; and the requirements of simplicity and directness of speech have led to the idea of the steady flux of time and to the habitual projection of this idea into every objective condition we encounter in nature.

Two phases of two systems are simultaneous or coincident in time when they involve the loss of energy by one of the systems and the gain of energy by the other system. Thus the idea of simultaneity rests fundamentally upon the principle of the conservation of energy. If energy could be taken from one system, temporarily annihilated, and later delivered to another system, our idea of simultaneity would have to be modified; or if energy is taken from one system and if some time must elapse before it is delivered to another system, as in the case of transmission of energy by a beam of light, then again a modified conception of simultaneity would have to be developed. Indeed this modified idea of simultaneity is already accomplished in terms of the idea that light has a definite velocity. It seems, however, that light does not have a definite velocity in the simple mechanical sense of the term velocity, and if so we are forced to the idea of simultaneity which is involved in the Lorentz-Einstein transformation.

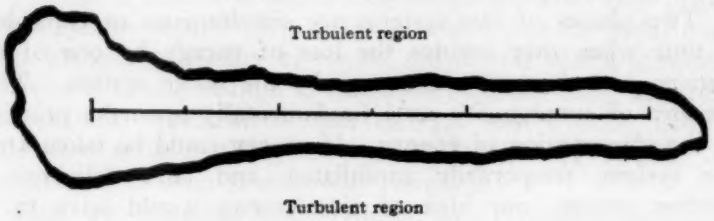
The idea that it is everywhere *now* cannot be justified in the physical nature of things although an assumption to that effect is extremely convenient in speech. Also the idea that time is a universal steady flux cannot be justified in the physical nature of things although an assumption to that effect is extremely convenient in speech. Indeed, throughout the above discussion,

modes of expression are used which involve the common idea of time as a steady flux and to avoid the use of these common modes of expression would make the discussion extremely difficult to follow.[14]

THE IDEA OF SPACE.

Our idea of extension in space is undoubtedly based upon measurement, and perhaps the rough measurement by steps in walking is the kind that has had most to do with the growth of our idea of space. If we wish to subject our idea of space to criticism, however, we must consider the most careful of length measurements, and such measurements are limited in precision by the turbulence of the material through which and

FIG. 14.



by which the measurements are made. In a certain strict sense a turbulent region has no dimensions, to attempt to measure such a region a quiescent region must be projected into it as indicated in Fig. 14. This matter may be more clearly illustrated by Fig. 15 which represents a turbulent region surrounded by a quiescent shell. The turbulent region has no volume, to measure what we would call its volume all of our measurements would be made on or in the shell and therefore the cubic contents or volume is a property of the shell.

Measurements of length beyond the range of the yardstick are made indirectly, by triangulation, and lines of sight are

[14] In this discussion of time we have left untouched the question as to what may be the physical differences in nature which correspond to passage of time. This matter is discussed by the present writer in a brief paper entitled, "Entropy and Time," in *Physical Review*, vol. xxx, pages 766–775, June, 1910.

always used in such work. No one can therefore deny that space so measured must be subject to all the peculiarities of light transmission. If light transmission requires the shortening of space in a moving system in a direction parallel to the

FIG. 15.

motion; why, then space is thus shortened and that is all there is to it. At least that is all there is to the question of shortening of triangulated space. As to the shortening of *B*'s yardstick in Figs. 8, 9, 10, 11, 12 and 13, this again is largely a question of what *A* sees and that settles it.[15]

---

[15] This matter is discussed rather minutely by G. N. Lewis and R. C. Tolman, *Philosophical Magazine*, vol. 18, pages 510–523, October, 1909.

Petroleum Production of the United States in 1910. OIL, PAINT AND DRUG REP. (From *U. S. Geol. Surv. Bull.*, Jan. 30, 1911.)—In the year 1910, new oil supplies have been developed in the United States, more than enough to keep up the country's production of the last three years. The production increased to over 200,000,000 barrels, which is two-thirds of the world's supply and several million more barrels than the whole world produced seven years ago. The greatest developments were in the Sunset-Midway district of California, and in the Caddo field of Louisiana. Both these developments caused important changes in the conditions of marketing the oil. The total production as reported by D. T. Day, of the U. S. Geological Survey, was about 200,000,000 to 208,000,000 barrels, approximately distributed as follows:

Illinois	32,000,000
Appalachian and Lima (Indiana) fields	32,000,000
Gulf and Caddo fields	14,000,000
Mid-continent and Rocky Mountain fields	53,000,000
California	73,000,000
	204,000,000

Stocks increased over 50 per cent. on the Pacific coast. Prices of crude oil declined, except in the mid-continent field, where they increased to 44 cents a barrel.

The following figures show the exports of mineral oils:

	Gallons, 1909	Gallons, 1910
Crude	128,239,923	119,630,159
Illuminating	1,039,742,219	932,343,617
Naphtha	57,555,061	79,059,528
Lubricating and paraffin	157,147,914	158,866,676
Residuum	114,109,989	107,095,460
Total	1,496,795,106	1,396,995,440

Chromax Bronze, a New Alloy. ANON. (*Metal Ind.*, ix, 41.)—This is an alloy of chromium, copper and nickel. It is claimed to be the only copper alloy which contains chromium, and is protected by patents. As chrome-nickel-steel is recognized as the best steel, so this bronze is claimed to be superior to any other. As a bearing metal it is said to be unrivalled, and it has a high fusing point of 1200° F. It will not fuse nor cut even if raised to red heat by friction. It will stand 20,000 pounds pressure per sq. inch on a 6-inch bearing surface at slow speed. It takes on a high polish and will not crystallize. It has a tensile strength of 79,000 pounds per square inch with an elongation of 3.3 per cent. and is extremely dense. It is acid proof, non-corrosive and is not affected by seawater. It can be rolled into sheets and wire.

ON THE DURATION OF ELECTRICAL CONTACT BETWEEN IMPACTING SPHERES.

BY

A. E. KENNELLY, Sc.D.,

Harvard University

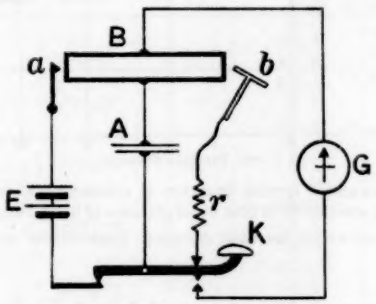
AND

EDWIN F. NORTHRUP, Ph.D.,

Palmer Physical Laboratory, Princeton University.

In the *Philosophical Magazine* for May, 1876, Mr. Robert Sabine described "A Method of Measuring very small Intervals of Time," involving the determination of the loss of charge from a well insulated condenser through a non-inductive path of known resistance, closed for the very brief interval to be measured. In particular, the time of contact of a light hammer impacting on

FIG. 1.



Connections of Sabine's apparatus for measuring the duration of impact between hammer and anvil.

an anvil was measured in this way. Fig. 1, which is taken from that paper, represents at *B* a block of metal, or anvil, against which the contact, *a*, is pressed, in order to charge the condenser *A* from the battery *E*. The light hammer, *b* (weighing about 30 grammes), is then suddenly struck against *B* and allowed immediately to rebound. During the interval of contact between *B* and *b*, the condenser leaks through the resistance *r*, and the charge remaining in the condenser is measured by depressing

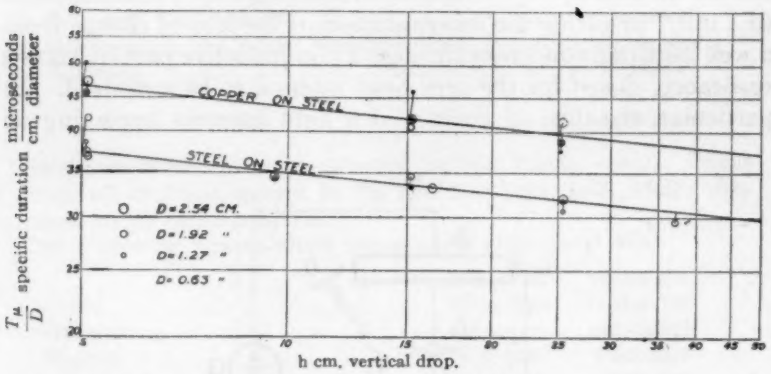
the key K and noting the deflection on the scale of the ballistic galvanometer G.

The formula applying to such a case is well known to be:

$$t = cr \log_e\left(\frac{Q}{q}\right) \quad \text{seconds,} \quad (1)$$

where Q is the intitial charge of the condenser in coulombs, q the charge remaining after the impact, c the capacity of the condenser in farads, and r the resistance of the discharging circuit in ohms. In the particular instance cited by Sabine $c = \frac{1}{3} \times 10^{-6}$ farad, $r = 1000$ ohms, $Q / q = 1.163$, $\log_e 1.163 = 0.151$, and $t =$ 0.000050 second or 50 microseconds.

FIG. 2.



Graphs of observations on the specific duration of contact between copper balls and also steel balls impinging on a steel anvil, in four different sizes of balls. Ordinates specific duration $\frac{T_\mu}{D}$. Abscissas, height from which the balls dropped. Logarithmic co-ordinates. Sets 1 and 2, Table I.

This Sabine apparatus was exhibited in London in 1876, and its operation witnessed by the first of the present writers, who repeated the experiments in February, 1889, using, however, a number of metallic spheres of different sizes and substances, in place of a hammer. A fine copper wire was fastened to the sphere under test, which was then dropped on the upper hardened steel surface of an anvil from a measured height. As in the Sabine experiment, a ballistic galvanometer was used to measure the condenser charges Q, q, before and after impact. The results obtained are given for the steel and copper balls in Table I and in Fig. 2. The results with the balls of other

metals were very irregular, apparently owing to permanent deformation under the impact stresses, and are omitted. The last column in Table I gives the ratio of the computed duration of impact in millionths of a second to the diameter of the ball in cm. This ratio may be called the "specific duration." It

TABLE I.

MEASUREMENTS IN SERIES I. OBSERVER K.

Ball number	Set number	Metal	Ball diameter, D., cm.	Drop, cm.	Impact duration, T_μ microseconds	Specific duration, $\frac{T_\mu}{D}$ microseconds / diameter
1	1	Steel	2.54	5.1	94.5	37.2
				9.7	87.5	34.5
				16.3	84.0	33.1
				25.4	81.0	31.9
2	1	Steel	1.92	5.1	70.5	36.9
				15.2	66.3	34.6
				37.0	56.5	29.5
3	1	Steel	1.27	5.1	49.0	38.6
				9.7	44.0	34.6
				25.4	39.0	30.7
4	1	Steel	0.63	15.2	21.0	33.1
				25.4	20.0	31.5
5	2	Copper	2.54	5.1	120.0	47.2
				15.2	106.0	41.7
6				25.4	106.0	41.7
	2	Copper	1.92	5.1	80.0	42.0
				15.2	77.0	40.4
				25.4	74.0	38.9
7	2	Copper	1.27	5.1	58.0	45.7
				15.2	53.0	41.7
				25.4	49.0	38.6
8	2	Copper	0.63	5.1	32.0	50.4
				15.2	29.0	45.7
				25.4	24.0	37.8

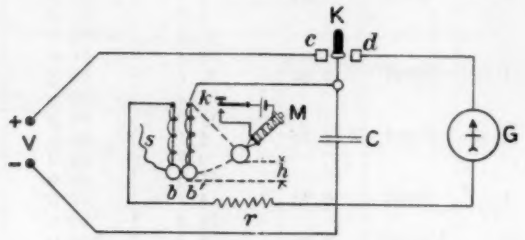
will be seen that the duration was at least very nearly proportional to the ball's diameter at any given drop or height from which the ball fell upon the anvil, and also that the greater the drop, the shorter the duration, but that increasing the drop five times only decreased the duration about 16 per cent. The durations with the copper balls were all about 25 per cent. greater than with the steel balls, for the same diameter and drop; and

the durations also were more irregular with copper than with steel balls, apparently owing to the softer quality of the metal. If the copper balls fell from a height exceeding 20 cm. they were liable to become dented, or permanently deformed.

The above results were not published at the time; but were briefly described in a lecture given by the first writer at Cornell University in 1891, at which lecture the second writer was present. The fact was noted that the duration of impact increased with the size of the ball; but was not much influenced by the drop; or, therefore, by the velocity at impact, within the range here considered.

In October, 1910, the second writer set up the apparatus, for making the measurements as a laboratory class-room exer-

FIG. 3.



Connections of apparatus in second series of tests.

cise, except that instead of using a ball impinging on an anvil, two similar and equal balls were suspended in such a manner that one was allowed to impinge on the other, as shown diagrammatically in Fig. 3. The balls b b' were of smooth hard steel, like bicycle balls, each having a diameter of 5.08 cm., a mass of 538.6 grammes and, therefore, a density of 7.865. The releasing electromagnet M was held in a clamp, and could be set at any desired position. With key k closed, the magnet would support ball b' at any desired height h cm. above its lowest position. On opening the key k, the ball b' would be released, would swing down against ball b, and, on colliding, come to rest; while ball b, after the impact, would take up the motion of b'. It was prevented from swinging back and striking b' a second time by being held up with the silk string s; r was an accurate, non-

inductive resistance which could be given various values. *C* was a high-grade mica condenser of one microfarad. *G* was a ballistic galvanometer. It was proved by careful experiment to give throw deflections over its entire scale which were closely proportional to the quantity of electricity discharged through it. Calling a deflection of 262 scale divisions the standard deflection, the percentage errors for other deflections were as follows:

Divisions, deflections.	Per cent. error.
105	—.40
157	—.33
262	0
314	—.3
366	—.36
418	—.23
460	—.06

It was therefore considered, in view of the nature of the experiment, and other sources of error, that the galvanometer throws might be accepted as proportional to the electric quantities discharged. *K* was a highly insulated key, which would charge *C*

TABLE II.

SET NO. 1. OBSERVER N.

Height constant at 2.01 cm. Resistance varied. Condenser charged to 4 volts.

Discharge resistance, ohms r.	d_1	d_2	Duration of contact, seconds	Specific duration, microseconds, $\frac{T_\mu}{D}$
200	423.5	190.5	.0001598	31.45
500	423.5	307.4	.0001600	31.49
1000	423.5	359.7	.0001620	31.89
5000	423.5	409.5	.0001680	33.07

when the lever made contact with *c*, insulate *C* when it was in its midway position, and discharge *C* through the galvanometer when it made contact with *d*.

All connections needing high insulation were made with wires in air and supported on glass rods. The condenser was charged first to 4 volts, then immediately discharged, and the throw of

the galvanometer noted. This was repeated, but with the condenser left insulated for sixty seconds. The leakage of the condenser and wiring was thus found to be too small to require consideration.

After this preliminary work, two sets of measurements were made—set number one (Table II), in which the height of fall of the ball b' was kept constant, the resistance r varied, and the corresponding time of impact calculated, and set number two (Table III), in which r was kept constant at 500 ohms, and the height through which b' fell varied and the corresponding times of impact calculated. These heights, through which b' fell, were all measured with sufficient precision by means of a catheto-

TABLE III.

SET NO. 2. OBSERVER N.

Resistance constant at 500 ohms. Height varied. Condenser charged to 4 volts.

Height in cm. h	d_1	d_2	Duration of contact, seconds	Specific duration, microseconds, $\frac{T_\mu}{D}$
43.48	424.7	334.6	.0001192	23.46
25.46	424.7	327.2	.0001304	25.46
8.41	424.7	317.3	.0001458	28.70
3.96	424.7	308.3	.0001602	31.58
1.92	420.7	300.8	.0001677	33.01

meter. All measurements of throw deflections were repeated for each resistance and each height about ten times, and the means taken.

The times of impact were all calculated by relation (1) modified as follows, so as to give numerical results easily.

$$T_\mu = 2.3026\, r C_\mu \log_{10} \frac{d_1}{d_2} \quad \text{microseconds.} \quad (2)$$

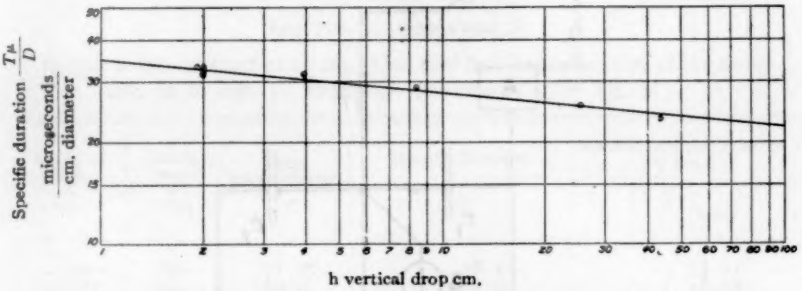
In (2) r is in ohms, C_μ is in microfarads, and equalled 1 microfarad; d_1 was the throw deflection with voltage to which the condenser was charged and then immediately discharged, the balls not having been in contact, d_2 was the throw deflection, the condenser having been charged to precisely the same potential, and then immediately discharged, but after the balls had collided.

The potentials applied to the condenser were at all times very accurately known, being determined with a potentiometer.

Tables II and III with the curve in Fig. 4 give all the essential facts brought out by the series of experiments.

The results recorded in Table III indicate that the duration of impact is distinctly increased as the height and impinging velocity of the falling ball are decreased. It was supposed that this conclusion might not be in conformity with the conclusions of the first writer. A comparison was therefore made, jointly, of the new sets of observations with those made in 1889. It was found that when both sets were marked off graphically on

FIG. 4.



Graph of observations on specific duration of contact between steel balls impinging on steel balls. Ordinates specific duration $\frac{T_\mu}{D}$. Abscissas, height from which the balls dropped. Logarithmic co-ordinates. Sets 1 and 2, Tables II and III. Diameter of balls, 5.08 mm.

logarithm paper, as in Figs. 2 and 4, with abscissas of $log_{10}\ h$ and ordinate $log_{10}\ (T_\mu/D)$ they agreed in giving substantially straight-line graphs, descending 1 unit in ordinate to 10 in abscissas, or corresponding to the general formula:

$$\frac{T_\mu}{D} = \frac{a'}{h^{\frac{1}{10}}} \qquad \frac{\text{microseconds}}{\text{cm. diam.}} \qquad (3)$$

Doubling the vertical drop of the impacting sphere thus increases the duration of impact only $\frac{1}{2}^{\frac{1}{10}}$ or 7.16 per cent.

In view of the above substantial coincidence of results between series 1 and 2, both as to the effect of the duration of varied diameter, and as to the effect of varied height, the latter relation being apparent for the first time, it was decided that a third series of observations should be made with increased care, and the second writer undertook this experimental work.

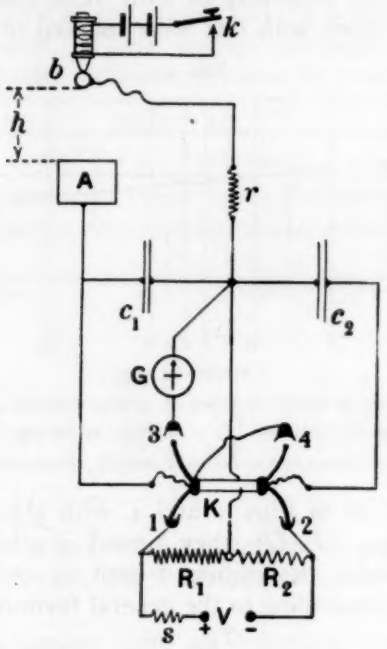
This work was made possible through the facilities provided by the Palmer Physical Laboratory, Princeton, N. J.

The experiments of the first writer were made with the facilities of Mr. T. A. Edison's laboratory.

DETAILS OF THE THIRD SERIES OF OBSERVATIONS.

Seven sizes of hard polished steel balls were prepared between the diameter limits of 2.54 and 6.35 cm. (1 in. and 2½

FIG. 5.



Connections of apparatus in third series of tests.

in.). The impact was made in the first set of measurements between pairs of equal balls with constant drop, in the second set between pairs of equal balls with different drops, and in a third set, between a ball and a mass of hard steel armor plate 33 x 33 x 22.9 cm., weighing 191.6 kg. In a short fourth set, a ball was dropped on a hardened steel anvil weighing 45.3 kg.

The measurement of the loss of charge during impact was made in all cases by the method of charge mixture, instead of by

ballistic galvanometer deflections, so as to substitute a null method for a deflection method. That is, the charge left in the condenser after the impact was nearly neutralized by mingling it with a suitable known charge of opposite sign, the small residue of incomplete neutralization being then measured by the galvanometer.

The connections for the test are indicated in Fig. 5. c_1 and c_2 are two nearly equal condensers of accurately known capacity (0.5 microfarad); r is the adjustable, non-inductive resistance in the discharging circuit, A the block on which the ball, b, impinges. The rocking switch, K, when turned downwards as

TABLE IV.

SET NO. 1. OBSERVER N.

Height of fall constant at 10 cm. One steel ball strikes another of the same size, as in Fig. 3. Discharge connections as in Fig. 5.

Diam. of balls, D cm.	Disch. res., r ohms	Time, microseconds, T_μ	Specific duration, $\frac{T_\mu}{D}$	Specific duration referred to $h = 1$, $\left(\frac{T_\mu}{D}\right)_{h=1}$
2.54	716	71.57	28.18	35.47
3.175	893	89.0	28.03	35.28
3.81	1075	107.5	28.21	35.51
5.08	1402	140.2	27.60	34.74
			Mean 28.005	Mean 35.25

shown, charges the two condensers to potentials of opposite sign with quantities directly proportional to R_1 and R_2. These resistances were so adjusted that the value in ohms of the discharge resistance should be ten times the duration of the impact in microseconds, subject to a small correction for any residual discharge.

On throwing over the rocker slowly, the two condenser charges were first mingled through contact 4, and then the residue was discharged through the galvanometer by contact 3.

Third Series, First Set.—Table IV records the mean of observations on the duration of impact between balls of the same size, for pairs of different diameters, and with constant height of fall. It will be seen that the specific duration (T_μ/D), is nearly constant.

Third Series, Second Set.—Table V contains the results of a series of measurements with one pair of steel balls 5.08 cm. in diameter, one ball being suspended at rest, and the other allowed to impinge, by swinging against it from a measured height.

Third Series, Third Set.—In this set the connections were the same as in Fig. 5. Seven different sizes of steel balls were dropped from the same height (25 cm.) upon the bright surface of a mass of hardened steel armor plate 33 x 33 x 33.9 cm.

TABLE V.

SET NO. 2. OBSERVER N.

Duration and Specific Duration of Impact between two hard steel balls each 5.08 in diam., one being allowed to swing against the other from different elevations.

Vertical drop, h cm.	Resistance in disch. contact, r ohms	Galv. sensibility, divs. per ohm.	Duration of contact, T_μ microseconds	Specific duration of contact, $\frac{T_\mu}{D}$ microseconds / cm. diam.
0.002	3800.0		380.0	74.8
0.1	2360.0	0.085	235.7	46.39
1.0	354.0	2.2	176.6	34.76
1.0	1800.0	0.13	179.0	35.23
1.92	1800.0		167.7	33.01
2.0	1682.0	0.14	167.9	33.05
3.96	1682.0		160.2	31.53
5.0	1541.0	0.16	153.9	30.29
8.41	1541.0		145.8	28.7
10.0	1402.0	0.26	140.2	27.6
15.0	1368.0		136.7	26.91
20.0	1316.0		131.7	25.92
25.0	250.5		126.0	24.8
25.0	1265.0	0.3	126.6	24.92
25.46			130.4	25.67
35.0	1254.0		125.5	24.70
40.0	1230.0		123.2	24.25
43.48			119.2	23.46

weighing 191.6 kg, so as to rebound after a single impact. The observations are recorded in Table VI.

Third Series, Fourth Set.—In this set the connections were the same as in Fig. 5. Two different sizes of balls were dropped from the same height (25 cm.) on the hardened steel surface of an anvil weighing 45.3 kg. The surface of the anvil was harder

than that of the armor plate used in the preceding set. The observations are recorded in Table VII.

General Observations Concerning the Graphically Plotted Observations.—It will be observed that in each of the three

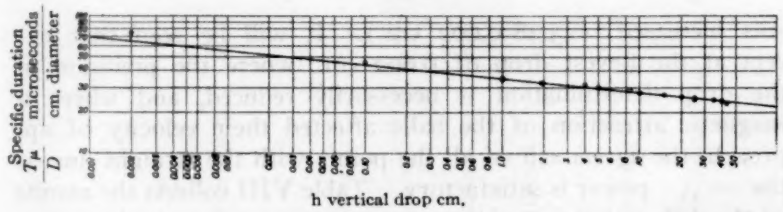
TABLE VI.

SET NO. 3. OBSERVER N.

Diameter of falling ball, D cm.	Resistance in disch. circuit, r ohms	Galv. sensibility divs. per ohm	Duration of impact T_μ	Specific duration, $\frac{T_\mu}{D}$ microseconds / cm. diameter	Specific duration at 1 cm. $\left(\frac{T_\mu}{D}\right)_{h=1}$ microseconds / cm. diameter
2.54	150.0	4.6	74.7	29.41	40.59
3.175	185.5	3.2	92.7	29.20	40.28
3.81	222.0	2.8	111.1	29.16	40.23
4.445	261.0	2.6	130.5	29.36	40.51
5.08	409.0	2.6	146.6	28.86	39.81
5.08	295.1	2.0	147.5	29.03	40.05
5.715	333.2	2.0	166.6	29.15	40.22
6.35	370.0	1.6	185.0	29.13	40.19
			Mean	29.16	Mean 40.23

series, the observations as plotted in Figs. 2, 4 and 6, substantially conform on logarithm paper to straight lines whose inclination

FIG. 6.



Graph of observations on specific duration of contact between two hard steel balls, each 5.08 cm. in diameter, one being allowed to swing against the other from different elevations h cm. Ordinates specific duration $\frac{T_\mu}{D}$. Abscissas elevation h. Logarithmic co-ordinates. Third series of measurements. Second set. Table V.

is 1 in ordinates to 10 in abscissas. That is, the specific duration varies inversely as the $\frac{1}{10}$ power of the vertical drop. In the first series (Fig. 2), the deviations of the observations on either

side of the straight line are appreciable, especially with some of the copper balls, and each recorded observation represents in most cases the mean of only two successive trials. In the second series (Fig. 4), the degree of precision was greater. The method of observation was the same as was used in the first series (ballistic galvanometer deflections); but more numerous trials were made in order to obtain each mean recorded observation. In the third series (Fig. 6), taken after this straight-line graph had been discovered, care was taken to subject this graph to a critical test. A null method was substituted for the deflection method of measuring, numerous observations were made for each point on the graph, and the range of vertical drop

TABLE VII.

SET NO. 4. OBSERVER N.

Diam. of falling ball, D cm.	Resistance in disch. circuit, r ohms	Galv. sensibility, divs. per ohm	Duration of impact, T_μ microseconds	Specific duration, $\frac{T}{D}$ microseconds / cm. diam.	Specific duration at 1 cm, $\left(\frac{T_\mu}{D}\right)_{h=1}$ microseconds / cm. diam.
2.54	151.6	2.24	75.8	29.84	41.17
5.08	308.0		154.0	30.315	41.83
				Mean 30.08	Mean 41.5

was increased (43.48:0.002 cm.). It will be seen that except at the lowest drop of 0.002 cm., where the precision in the drop determination is necessarily reduced, and where a magnetic attraction of the balls affected their velocity of approach, the agreement of all the points with the straight line of the $-\frac{1}{10}$ power is satisfactory. Table VIII collects the results of the different series of measurements.

Possible Application of the Results.—Since it would appear from the above series of observations that the duration of contact between impacting steel spheres follows, at least approximately, a definite law between the range of 0.002 to 43 cm. for h, and of 0.63 to 5.08 cm. for diameter, the opportunity seems open to employ this result for obtaining definite and predetermined small intervals of contact in electric circuits under con-

TABLE VIII.

COLLECTING THE RESULTS OF THE DIFFERENT SERIES OF MEASUREMENTS.

Series	Date of series	Set	Observer	Nature of test	Table	Specific duration formula	Fig.	Range of h, cm.	Range of D, cm.
First	Feb. 1889	1	K	Steel balls on steel anvil	I	$44/h^{1/5}$	2	5 to 37	0.63 to 2.54
		2	K	Copper balls on steel anvil	I	$55/h^{1/5}$	2	5 to 25	0.63 to 2.54
Second	Oct. 1910	1	N	Steel ball on steel ball	II	$34.3/h^{1/5}$	–	2.01	5.08
		2	N	Steel ball on steel ball	III	$35/h^{1/5}$	4	1.9 to 43.5	5.08
Third	Feb. 1911	1	N	Steel ball on steel ball	IV	$35.25/h^{1/5}$	–	10	2.54 to 5.08
		2	N	Steel ball on steel ball	V	$35.0/h^{1/5}$	6	0.002 to 43.48	5.08
		3	N	Steel ball on steel armor plate	VI	$40.2/h^{1/5}$	–	25	2.54 to 6.35
		4	N	Steel ball on steel anvil	VII	$41.5/h^{1/5}$	–	25	2.54 to 5.08

ditions where the spark at rupture can be either eliminated or controlled. No attempt has, however, been made, as yet, by the writers to use the result in this way.

Relation between Specific Duration and Velocity at Impact.—If we take the duration of impact between two equal steel balls from Series II and III as:

$$T_\mu = \frac{35D}{h^{\frac{1}{10}}} \quad \text{microseconds} \quad (4)$$

and substitute for h its gravitational velocity v $\frac{cm.}{sec.}$ according to the well-known relation:

$$h = \frac{v^2}{2g} \quad \text{cm.} \quad (5)$$

where g is the acceleration due to gravitation in $\frac{cm.}{sec.^2}$ we obtain:

$$T_\mu = \frac{35D\,(2g)^{\frac{1}{10}}}{v^{\frac{1}{5}}} \quad \text{microseconds} \quad (6)$$

$$= \frac{35\,D\sqrt[10]{1962}}{v^{\frac{1}{5}}} \quad \text{microseconds} \quad (7)$$

taking $g = 981$ cm. per sec.^{2} so that; since

$$\sqrt[10]{1962} = 2.1343,$$

$$T_\mu = \frac{74.7\,D}{v^{\frac{1}{5}}} \quad \text{microseconds} \quad (8)$$

or, in round numbers,

$$T_\mu = \frac{75\,D}{v^{\frac{1}{5}}} \quad \text{microseconds} \quad (9)$$

D ranging in the measurements from 0.63 to 5.08 cm., v from 2 to 292 cm. per sec., and T_μ from 20 to 380 microseconds.

Conclusions.—Within the limits of range and accuracy covered by the experiments, we may conclude as follows:

(1) If a metallic sphere impinges either upon another like metallic sphere, or upon a hard flat steel surface, the duration of impact is proportional to the diameter of the sphere.* Consequently, the duration per cm. of diameter or "specific duration"

* Although this experimental result has not previously been published, so far as the writers are aware, yet this particular fact seems not to be new. In particular, it has been known in the Jefferson Physical Laboratory, at Harvard University, for a number of years.

depends only on the nature and hardness of the metallic impacting surfaces, and on the velocity of impact. By referring then to specific duration, the influence of varying diameter, in what follows, can be eliminated.

(2) The harder the metals at their mutually impacting surfaces, the shorter the specific duration.

(3) The specific duration is roughly about 20 per cent. greater when a sphere impacts upon an anvil or stationary hard plane surface of a mass large as compared with that of the ball, than when it impacts with a stationary sphere of the same size. This increase in duration is attributable not only to the difference in relative curvature of the impacting surfaces; but also to the fact that in the former case the impinging ball has its velocity approximately reversed before breaking contact; whereas in the latter case the velocity of the impacting ball is merely reduced to zero, the initial velocity being communicated to the impacted ball.

(4) Whether the impacting ball strikes another like ball or an anvil, the specific duration of impact

$$\left(\frac{T_\mu}{D}\right)$$

varies inversely as the one-tenth root of the vertical drop h cm., or the one-fifth root of the impacting velocity, v cm. per sec. according to the formula :

$$\frac{T_\mu}{D} = \frac{a'}{h^{\frac{1}{10}}} = \frac{a''}{v^{\frac{1}{5}}} \quad \frac{\text{microseconds}}{\text{cm. diam.}} \tag{10}$$

where a' and a'' are constants depending on the nature and curvature of the impacting surfaces; such that

$$\frac{a''}{a'} = \sqrt[10]{2g} = 2.1343,$$

for $g = 981 \frac{cm.}{sec.^2}$.

For a copper ball on a steel anvil, $a' = 55$, $a'' = 117$ approximately.

For a steel ball on a steel anvil, $a' = 42$, $a'' = 90$ approximately.

For a steel ball on a steel ball, $a' = 35$, $a'' = 75$ approximately.

SYMBOLS EMPLOYED.

a', a'' = Constants in formula for specific duration.
c = Capacity of a condenser (farads).
C_μ = Capacity of a condenser (microfarads).
D = Diameter of sphere (cm.).
d_1, d_2 = Deflections of a ballistic galvanometer in discharging circuit (numeric).
e = 2.71828 .....
g = Gravitational acceleration $\left(\frac{cm.}{sec.^2}\right)$.
h = Height of descent of a sphere before impact (cm.).
Q = Initial charge of a condenser (coulombs).
q = Residual charge of a condenser (coulombs).
r = Resistance in discharging circuit (ohms).
t = Duration of partial discharge of condenser (seconds).
T_μ = Duration of partial discharge of condenser (microseconds).
v = Velocity of sphere at impact $\left(\frac{cm.}{sec.}\right)$.

BIBLIOGRAPHY.

Robert Sabine: "On the Measurement of very small Intervals of Time." *Telegraphic Journal*, May 15, 1876, vol. iv, No. 79, pp. 141–143. "A Method of Measuring very small intervals of Time." *Phil. Mag.*, ser. 5, May, 1876, vol. i, pp. 337–346.

H. R. Kempe: "Handbook of Electrical Testing," 1887, 4th ed, p. 329.

Mascart and Joubert: "Electricity and Magnetism," 1888, vol. ii, p. 282.

Devaux-Charbonnel: "Measurement of very short Time Intervals." *Comptes rendus*, May 14, 1906, 142, pp. 1080–1082. Science Abstracts (Physics), 1448 of 1906. *L'Electricien*, June 23, 1906, vol. xxxi, pp. 386–389.

B. O. Peirce: "Length of Time of Contact of a Quick Tap on a Telegraphic Key." *Proc. Am. Academy Arts and Sciences*, June, 1906, vol. xlii, No. 4, pp. 95–100.

Advantages of Abandoning All Guages. G. E. GODDARD. (*Amer. Mach.*, xxxiv, 400.)—Mr. Goddard in a thoughtful and clearly reasoned article points out the confusion and trouble arising from the numerous guages now used as standards, *e.g. Roebling's, Stub's* wire guage, the *B. W. G.*, the *Brown and Sharpe*, the *U. S. Standard*, the *Morse* steel wire, and the *British* steel wire guages; and suggests instead of these different guages the use of *decimal measurements only*. This action has been already recommended by two national societies, the American Society of Mechanical Engineers, and the American Railway Master Mechanics Association. Such a course as the adoption of one, and only one, standard guage would save much time and money and avoid numerous misunderstandings and consequent errors and delays.

ELECTRIC TRANSIENTS.

BY

DR. CHARLES PROTEUS STEINMETZ.

1. WITH the increasing size and importance of electrical systems, those phenomena, which temporarily occur in all electrical circuits, as oscillations, surges, electrical impulses and travelling waves, are becoming of increasing frequency and destructiveness, and a knowledge and understanding of their general nature and characteristics, and the cause of their origin, has become important and necessary for the electrical engineer.

While the theory of these electrical transients is still far from complete, and involves considerable mathematics, it is possible to gain an insight into their cause and origin, their nature and general characteristics, and even their most important numerical relations, without theoretical mathematics, and in view of the great and rapidly increasing importance of these phenomena, in the following an attempt is made to give without the use of mathematics a general discussion of them, and their bearing on the operation of electrical systems.

2. In general, an electric circuit comprises a source or generator, a line and a load. In the generator, electric power is produced from some other form of power, as mechanical, and flows over the line into the load where it is used. Not all the electric power produced by the generator reaches the load, but a part is consumed throughout the entire circuit, dissipated as heat by the resistance of the conductor: ri^2.

This however does not yet constitute the entire phenomena which we will call the flow of electric power, but there also is something going on in the space outside of the conductor which directs the flow of electric power: there is a *magnetic field*, lines of magnetic force encircle the conductor; and there also is an *electrostatic* or *dielectric field*, lines of electrostatic or dielectric force radiate from the conductor, and the magnetic field, and the electrostatic or dielectric field in the space outside of the conductor are just as essential parts of the flow of the electric power, as the power dissipation in the resistance of the conductor.

The magnetic field is proportional to the current i, with a proportionality factor which is called the *inductance* L of the circuit, and thus is Li; the dielectric field is proportional to the voltage e, with a proportionality factor which is called the *capacity* C of the circuit, and thus is Ce.

The magnetic field and the dielectric field represent *stored energy*: the energy stored by the magnetic field is

$$\frac{Li^2}{2},$$

and that stored by the dielectric field is

$$\frac{Ce^2}{2}.$$

Before a steady current can flow in a circuit, energy must therefore be supplied in producing its magnetic field; before a steady voltage can be on the conductor, energy must be supplied in producing its dielectric field. This energy is supplied by a flow of power from the conductor into the surrounding space in which the field exists. As the magnetic field is proportional to the current, the power required to supply its energy is given by a voltage, the *inductance voltage;* as the dielectric field is proportional to the voltage, the power required to supply its energy is given by a current, the capacity current, and inductance voltage and capacity current thus are the phenomena, by which the stored energy of the magnetic and dielectric fields respectively is supplied to the space surrounding the conductors.

Whenever a change occurs in an electric circuit, which involves an increase of its stored magnetic or dielectric energy, as an increase of current or of voltage, power flows from the circuit into the surrounding space, until the stored energy has been supplied, and inversely, whenever a change occurs, which requires a decrease of the stored energy, power flows back from space into the circuit. This power flow is temporary, lasts only until the required stored energy has been supplied, or the surplus stored energy returned to the circuit, and thus it is called a *transient.*

Transients therefore are the phenomena, by which at a change of circuit condition the stored energy readjusts itself to the changed condition, and any change in an electric circuit, which

requires a change of the stored energy, cannot occur instantly, but a transition period of the readjustment of the stored energy intervenes, before stationary conditions are reached, whether in a direct or alternating current circuit.

3. It is obvious, that transients are not a specifically electrical phenomenon, but occur in any system of forces, where energy storage occurs. Thus in a water power, energy is stored in the momentum

$$\frac{mv^2}{2}$$

of the moving mass of water in the supply pipe, etc., and any change of load, which requires a change of the flow of water and therefore of its stored energy, cannot be accomplished instantly, but a mechanical transient appears, and the problem of governing water powers, especially at high heads, is essentially the problem of taking care of the mechanical transient. In railroading, the periods of acceleration and of deceleration are nothing but the mechanical transients of the stored energy; the firing up and the cooling down of a steam boiler are thermal transients, etc.

In the preceding cases, energy is stored in one form only; as kinetic mechanical energy in the pipe line and the railway train, as heat energy in the steam boiler, and the only change of the stored energy, which can occur, is an increase or a decrease. If, however, energy is stored in two or more forms, in addition to the increase or decrease of stored energy, a transformation of stored energy from one form to another may occur, and usually does occur. This for instance is the case in the pendulum. When the weight of the pendulum comes to rest, in its end position, it contains stored potential energy of gravitation, due to its elevation above the lowest position. When the weight reaches the lowest position, all this potential energy has vanished; some has been dissipated by friction, but most converted into kinetic energy of motion, and the weight now contains stored kinetic energy. During its further motion, this kinetic energy is again converted into potential energy, until the weight comes to rest in the next end position, and so on, and gradually, by a series of periodic transformations between potential energy of elevation and kinetic energy of motion, the stored energy of the pendulum is dissipated.

Two classes of transients thus exist: single energy transients, in which energy is stored in one form only, and the phenomenon is a steady increase or decrease of the stored energy, and double energy (or multiple energy) transients, in which in addition to an increase or decrease of the stored energy, a transformation of stored energy between its two forms occurs, which usually is periodic.

4. In electric distribution circuits of 110 to 220 volts, in 600 volt railway circuits, and even in 2200 volt primary distribution circuits, the delectric energy

$$\frac{Ce^2}{2}$$

is still so very small compared with the magnetic energy

$$\frac{Li^2}{2},$$

that the former can be neglected compared with the latter (except under special conditions, as with lightning discharges, etc.) and the circuit can be considered as storing energy in one form only, as magnetic energy. The transients of such circuits thus are single energy transients, that is, a steady increase or decrease of the stored magnetic energy during the transition period after a circuit change. The dielectric energy becomes comparable in magnitude with the magnetic energy, in transmission lines of 30,000 volts and over, and in underground cables of 10,000 volts and over, and such high voltage circuits then give double energy transients, that is, surges of the stored energy. This is the reason for the appearance in high voltage circuits, of electrical disturbances different from those met in low and medium voltage circuits.

The single energy transients of electric circuits, which result from the stored magnetic energy, are rarely of serious importance: as they are a gradual change from the previous to the after conditions of the electric circuit, their inductive effects are usually small; due to the limited extension of such low and medium voltage circuits, their energy is moderate, and due to the relatively large resistance of most such circuits, the energy is rapidly dissipated, that is, the duration of the transient short, and they usually require consideration only to avoid the annoyance which may be caused by them. For instance, when closing

the field exciting circuit of a shunt motor, an appreciable time—frequently several seconds—elapses before the magnetic field has built up, and if then the armature is energized immediately and the armature rheostat cut out too rapidly, momentarily a big current may flow through the armature, without starting it, as the magnetic field is not yet there, and this current rush may blow the fuses.

Of serious moment such magnetic single energy transients become when of abnormally great energy, that is, in very extended systems or in highly inductive circuits, as motor fields, and especially, when forced to be of very short duration, as in the latter case, even with a moderate amount of energy, the power may be very great, since it is the energy divided by the time in which it is dissipated. The latter is the case with the opening transient of an inductive circuit. In opening an inductive circuit its stored magnetic energy must be dissipated. If then an inductive circuit were opened instantly, that is, its stored energy dissipated in an infinitely short time, this would represent infinite power, that is, infinite induced voltage, or in other words, the insulation of the circuit would be punctured. To a considerable extent, an inductive circuit protects itself against too rapid opening, by the arc following the switch blades: the more rapid the switch opens, the greater is the induced voltage, and the further the arc follows and maintains the circuit, that is, limits the rapidity of the circuit opening. The problem of switching inductive circuits thus is, to open the circuit sufficiently rapid to limit the burning of the switch contacts by the arc, but to open sufficiently slow to limit the induced voltage below the value which would seriously endanger the insulation. Inversely, if an inductive circuit is opened very rapidly, as by a powerful air-blast across the opening switch, or a small condenser shunted across the break, practically unlimited voltages are produced, as in the Ruhmkorff coil.

5. Occasionally magnetic transients are of importance not directly by their stored energy, but by the power production which they cause. A characteristic instance hereof is found in the momentary short circuit currents of alternators. The voltage of an alternator depends on the field excitation and the load, that is, the magnetizing or demagnetizing action of the armature current, which combines with the magnetomotive force of the field excit-

ing current to a resultant, and the latter produces the magnetic field flux. At open circuit, the magnetic field flux is that due to the field excitation alone. If now with the same field excitation, current is drawn from the armature, especially if it is a lagging current, the demagnetizing action of this current lowers the field flux and with it the voltage. At short circuit, the armature current—which then is lagging—rises to such a value, that its demagnetizing action lowers the field flux to a small fraction of the value which would exist with the same field excitation at open circuit: The value just sufficient to circulate the short circuit current in the armature. With modern high speed turbo alternators, the permanent short circuit current may be about 4 times full load current, and the field flux at short circuit may be as low as one-tenth of the field flux, which exists at open circuit with the same field excitation. In short circuiting the alternator, the field magnetic flux thus decreases to one-tenth its initial value. As it represents stored energy, it cannot do so instantly, but can decrease only gradually—though rapidly—from open circuit to short circuit value, and in the first moment after short circuit it thus still has practically full open circuit value, that is, a value, which may be ten times as great as the permanent short circuit value. As the latter gives a short circuit current in the armature equal to 4 times full load current, the former gives ten times as high a current, that is, a momentary short circuit current which may be as high as 40 times full load value. Thus, the effect of the magnetic field transient of the alternator is an excessive transient current rush in the armature at short circuit. Considering, that the permanent short circuit current of the armature, of 4 times full load value, demagnetizes the field so as to drop it to one-tenth of its value, the momentary short circuit current, of 40 times full load value, would demagnetize 10 times as much, and as at this moment of the beginning short circuit the field flux still has full value, the field current also must momentarily increase to 10 times its normal value, to maintain full field flux against the excessive demagnetizing action of the momentary short circuit current of the armature. That is, the magnetic field at the moment of short circuit begins to decrease at such a rate that by its decrease it induces in the field exciting winding an e.m.f., which raises the field current to the value required to hold the field flux against the armature reaction. Thus the momentary

current rush in the armature at short circuit, is accompanied by a corresponding current rush in the field. With single phase short circuit, this field current is pulsating with double frequency, as the single phase armature reaction pulsates with double frequency; with polyphase short circuit, a transient full frequency pulsation appears in the field current rush, corresponding to the starting transient of the armature current.

6. The most important, because most dangerous electrical transients are the double energy transients of high voltage circuits. In these circuits, in which the stored dielectric energy

$$\frac{Ce^2}{2}$$

is of the same magnitude with the stored magnetic energy

$$\frac{Li^2}{2},$$

the gradual increase of the total stored energy, at a change of circuit conditions, is accompanied by a surge, or transformation of the stored energy between its two different forms, similar as was illustrated on the pendulum as a surge between potential energy of gravitation, and kinetic energy of motion.

During the periodic transformation between magnetic and dielectric stored energy, the magnetic energy is a maximum,

$$\frac{Li_0^2}{2},$$

and therefore the oscillating current i a maximum i_0, at that moment, where all the energy is magnetic, that is, the dielectric energy

$$\frac{Ce^2}{2}$$

and therefore the oscillating voltage e is zero. The dielectric energy is a maximum,

$$\frac{Ce_0^2}{2},$$

and therefore the oscillating voltage e a maximum e_0, when during the periodic transfer of stored energy all the energy has become dielectric, that is, the magnetic energy

$$\frac{Li^2}{2}$$

and therefore the oscillating current i is zero.

It is however the same amount of stored energy (neglecting the gradual and slow decrease of energy by the power dissipation), which at one moment appears as magnetic, at the next moment as dielectric energy. That is, it is:

$$\frac{Li_0^2}{2} = \frac{Ce_0^2}{2}.$$

This *relation between the maximum value of the oscillating current, i_0, and the maximum value of the oscillating voltage, e_0,* is of the greatest industrial importance. It applies to all double energy transients, that is, surges of stored energy. Transposed, it gives:

$$\frac{e_0}{i_0} = \sqrt{\frac{L}{C}}$$

$\sqrt{\frac{L}{C}}$ is of the nature of an impedance, and is called the *natural impedance of the circuit,* and may be denoted by z_0:

$$z_0 = \sqrt{\frac{L}{C}}$$

in transmission lines, z_0 usually is between 200 and 600 ohms; it is must lower in cables, due to their high capacity C and low inductance L, and it is much higher in coiled circuits, as the high potential windings of high voltage transformers.

The great industrial importance of this relation between the maximum oscillating voltage and the maximum oscillating current is, that it allows the calculation of the one from the other. In most cases of electric surges of energy, one of the two quantities, the current or the voltage, is known, or can be estimated approximately, from the cause of the disturbance, and above relation allows the calculation of the other.

7. Consider for instance the switching on of a transmission line of 30,000 volts. With the switches open, the voltage on the line is zero; with the switches closed, the voltage has an effective value of 30,000, and thus a maximum value of $30{,}000\sqrt{2} = 42{,}400$ volts. That is, at the moment of closing the circuit, a sudden change of voltage occurs on the line which as maximum can amount to: $e_0 = 42{,}400$.

If then the natural impedance of the line, as calculated from the equations or from the tables of L and C of line con-

ductors is: $z_0 = 400$ ohms, the maximum oscillating current, which can be produced in the line by the operation of switching the dead line onto the live transformer is limited to:

$$i_0 = \frac{e_0}{z_0}$$

$$= \frac{42,400}{400}$$

$$= 106 \text{ amperes.}$$

Inversely, when a line carrying 30,000 volts is suddenly grounded, or short circuited, that is, its voltage changed from 30,000 volts effective, to zero, 106 amperes is the maximum current oscillation which may occur, and which, in case of short circuit, superimposes on the wave of the permanent short circuit current.

An interesting application of this relation is for the calculation of the maximum *lightning discharge* from a transmission line, against which the stations have to be protected. While the voltage of lightning may be practically unlimited, the maximum voltage which lightning can produce on the line obviously is limited by the disruptive strength of the line insulation against momentary voltages. If a higher voltage is impressed on the line by a lightning stroke (as frequently the case), it spills over at the next insulator, and if of sufficient energy, may puncture insulators, shatter cross arms and poles locally on the line, but the lightning discharge current, which rushes along the line towards the station, obviously is limited to the voltage which can actually exist, at least momentarily, on the line as result of the lightning stroke.

Assuming a 30,000 volt line: the insulators must be expected to stand continuously double voltage, or 60,000, and momentarily at least twice as much, or 120,000 to 150,000. Thus the lightning discharge current is limited to that given by the oscillating voltage of a maximum: $e_0 = 150,000$.

At a natural impedance of the line, of $z_0 = 400$ ohms, this gives:

$$i_0 = \frac{e_0}{z_0} = 375 \text{ amperes.}$$

Thus, 375 amperes is the maximum discharge current, which lightning could produce in this line, and thus the maximum cur-

rent, against which the lightning arresters in the station have to protect in case of a lightning stroke on the line near a station. If the lightning strikes at a considerable distance from the station, obviously the discharge current at the station is much less, as the energy of the oscillation is rapidly dissipated in its passage along the line.

Allowing a momentary rise of voltage at the station of 50 per cent., the maximum voltage drop across the lightning arresters should be limited to half the maximum line voltage, or 21,400 volts. At 375 amperes discharge, this allows an impedance of the lightning arrester and its discharge path, of

$$z = \frac{21{,}400}{375} = 57 \text{ ohms.}$$

To afford effective lightning protection, the resistance of the lightning arrester and impedance of its connection to line and ground should therefore not exceed 57 ohms in this case.

If however the natural impedance z_0 were much lower, due to the use of large conductors and relatively short distances between the conductors, for instance, $z_0 = 200$, and two parallel lines led from the station, then, if both lines were struck simultaneously, the natural impedance of the discharge would only be:

$$\frac{z_0}{2} = 100 \text{ ohms,}$$

and the maximum discharge current thus 1500 amperes, and thus would limit the permissable impedance of the lightning arrester circuit to 14 ohms. That is, either a very low resistance arrester and very low impedance discharge path becomes necessary, or the use of several lightning arresters and several line and ground connections in multiple, to afford protection.

8. As seen, without going into detail study of the lightning transients, considerable information can be derived from the above fundamental relation of current and voltage of the double energy transient.

Inversely, this relation may be applied to determine the oscillating voltage, which may be produced by a sudden change of current in the line. Assuming that the full load current of the 30,000 volts line is 200 amperes effective, that is, has a maximum value of $200\sqrt{2} = 283$ amperes. If then, in switching off

full load, the circuit would be broken at the maximum value of the current, the oscillation, which results, would be that due to a sudden change of current from 283 amperes to zero, that is:

$$i_0 = 283 \text{ amperes.}$$

At a natural impedance of: $z_0 = 400$ ohms, this gives a maximum oscillating voltage of:

$$\begin{aligned} e_0 &= i_0 z_0 \\ &= 283 \times 400 \\ &= 113{,}000 \text{ volts.} \end{aligned}$$

This is more than double voltage, that is, more than the voltage which the line can stand continuously, and already a moderate overload, as 50 per cent. would give an oscillating voltage higher than which the line could stand even momentarily, that is, would cause a flashover or a puncture of insulation.

Switching at or near maximum current thus is dangerous and frequently destructive, and the problem of controlling transmission lines is to devise a switching mechanism, which can be relied upon always to open the circuit at zero current. This is the reason which has lead to the development of the modern oil circuit breaker, as this type has the characteristic to open the circuit at the zero value of the current. It also has led to the abandonment of all types of air circuit breakers as dangerous on high voltage circuits, since the air circuit breaker cannot be relied upon to open always at zero current, but occasionally opens at or near maximum current, and then is liable to be destructive to the circuit insulation. The operation of the present extended high voltage systems thus has became possible only by the development of the modern oil circuit breaker.

As already the opening of full load current, when taking place at the wrong point of the wave, leads to dangerous voltages, it is interesting to see, what would be the result of opening a *short circuit* at or near maximum current.

Assuming the line impedance to be 20 per cent. at full load. That is, at full load current, the impedance voltage of the line is 20 per cent or one-fifth of impressed voltage. At short circuit, the total impressed voltage is consumed by the line impedance, and the short circuit current thus would be 5 times full load cur-

rent, provided that the generating system can maintain full voltage on the line at least momentarily, in case of short circuit at the end of the line. With a full load current of 200 amperes effective or 283 amperes maximum, the maximum short circuit current would thus be $5 \times 283 = 1415$ amperes, and if interrupted at the maximum value, would give an oscillation of maximum current: $i_0 = 1415$ amperes, thus, with a natural impedance of the line of $z_0 = 400$ ohms, on oscillating voltage of maximum value:

$$\begin{aligned} e_0 &= i_0 z_0 \\ &= 1415 \times 400 \\ &= 566{,}000 \text{ volts,} \end{aligned}$$

that is, far beyond the possible insulation strength of the line, or in other words, the line insulation, no matter how good, would be broken down in case of a short circuit being interrupted at or near the maximum value of current.

The most destructive transient of a high voltage circuit thus is the short circuit oscillation.

Occasional short circuits however are unavoidable in transmission lines, either due to accidents in apparatus, or due to flashovers on the line, at defective insulators, by atmospheric electrical disturbances, by heavy winds swinging the wires together, etc. As far as the short circuits are opened by the oil circuit breakers in the system, they are relatively harmless, due to the nature of the oil circuit breaker to open at zero current. More dangerous are flashovers on the line, resulting in flaring arcs, which lengthen and then blow themselves out. Fortunately, such flaring arcs only occasionally develop their destructive possibilities, but usually go out at the zero of the current wave: at the end of one half wave, the arc vapor stream cools sufficiently so that at the beginning of the next half wave the arc does not start again. Occasionally however such arcs blow themselves out explosively, by the rapid expansion of the air due to the heat of the arc, and as the heating effect is a maximum at or near maximum current, this explosive rupture of a flaring arc tends to occur near maximum current, and then produces a destructive oscillation. Especially is this the case in low reactance high capacity circuits, as cables, where the current and therefore the

heating effect in the flaring arc is very large and the arc inherently more unstable. Such flaring arcs thus constitute the most dangerous and destructive phenomenon of high voltage circuits.

It is interesting to note, that the surges resulting from a current transient are usually much greater in magnitude and thus in destructiveness, than those resulting from a voltage transient.

9. We have seen that in the surge of stored magnetic and dielectric energy, the current is a maximum when the voltage is zero, and inversely, that is, the oscillating current and the oscillating voltage are in quadrature, and the power thus is reactive, that is, surges to and fro, but there is no flow of power along the circuit. Such a surge of energy is called a *stationary oscillation, standing wave,* or *surge.*

Oscillating current and voltage may also be in phase with each other. Then there is a flow of power along the circuit, and the phenomenon is called a *travelling wave,* or an electric *impulse.* Travelling waves of high frequency frequently precede standing waves. Travelling waves have been observed of frequencies from a few hundred cycles, to millions of cycles; the former by oscillograph, the latter by spark gap across a small reactance.

In circuits comprising sections of different character, as transmission line, transformer, load, etc., that is, in most industrially important cases, the energy surge is a combination of standing waves and travelling waves. The energy surge obviously must die down simultaneously in all circuit sections. In some circuit sections however, as the transmission line, energy dissipation occurs at a greater rate than in other circuit sections, as transformer coils, and left separate, the surge would die down in the line much more rapidly than in the transformer. Thus, when line and transformer are connected together energy must be supplied to the line, from the stored energy of the transformer, by a travelling wave. Thus in the energy surge, or the transient of such a compound circuit, a flow of oscillating power occurs between the circuit sections. This results in a transformation of the oscillating voltage and current at the transition point between the successive circuit sections.

For instance, if a travelling wave passes from a transmission line into the high potential winding of the step-down trans-

former, and e_1 is the maximum voltage, i_1 the maximum current hence

$$p_1 = \frac{e_1 i_1}{2}$$

the power of the wave in the transmission line, e_2 the maximum voltage and i_2 the maximum current hence

$$p_2 = \frac{e_2 i_2}{2}$$

the power of the wave in the transformer; as the same power leaves the line which enters the transformer, it must be

$$\frac{e_1 i_1}{2} = \frac{e_2 i_2}{2}$$

e and i are however related by the natural impedance of the circuit section, that is:

$$\left.\begin{aligned} i_1 &= \frac{e_1}{z_1} \\ i_2 &= \frac{e_2}{z_2} \end{aligned}\right\} \qquad (2)$$

where z_1 is the natural impedance of the line, and z_2 the natural impedance of the transformer,

Substituting (2) in (1) gives:

$$\frac{e_2}{e_1} = \sqrt{\frac{z_2}{z_1}}$$

That is, *at the transition point between two circuit sections, a transformation of voltage occurs, with a transformation ratio, which is the square root of the ratio of the natural impedances of the two circuit sections, and a transformation of currents by the inverse ratio:*

$$\frac{i_2}{i_1} = \sqrt{\frac{z_1}{z_2}}.$$

This relation between the oscillating voltages and currents in different circuit sections is of fundamental importance in tracing their origin and destructiveness.

Hence, a travelling wave, coming from one circuit section into another circuit section of higher natural impedance, increases in voltage and thereby in destructiveness, and inversely, when entering a section of lower natural impedance, it decreases in voltage.

Thus, if a travelling wave of $e_1 = 30{,}000$ volts comes from a line of natural impedance $z_1 = 400$ ohms, into the high potential winding of a transformer, of natural impedance $z_2 = 3600$ ohms, it rises in voltage to:

$$e_2 = e_1\sqrt{\frac{z_2}{z_1}}$$

$$= 30{,}000\sqrt{\frac{3600}{400}}$$

$$= 90{,}000 \text{ volts.}$$

10. Electrical disturbances, originating in one circuit section, frequently develop their destructiveness in adjacent circuit sections, in which due to the higher natural impedance of the latter section they have risen to destructive voltages. The result, and the indication of a transmission line disturbance thus often is the break down of the transformers connected to the line, not because the transformers are weaker in insulation, but because the disturbance, while of harmless voltage in the line, has in entering the transformer risen in voltage to destructive values.

When speaking of voltage transformation at the transition point between two circuit sections, it is obvious that at the transition point the voltage is the same in both circuits, but a change of phase occurs, which results in a different maximum voltage some distance further on in the circuit, at the point where the voltage maximum occurs. With a voltage increase, this maximum is approximately a quarter wave distant from the transition point, and depending on the frequency of the wave, this point may be very near the transition point, with very high frequency waves, or far distant, with lower frequencies. Thus transformers may break down in the middle of their winding, as result of disturbances in the transmission line to which they are connected, if the disturbance is of moderate frequency, while the break down would occur in the end turns, if the disturbance in the line is of very high frequency. That is, the location of a break

down in a transformer does not indicate, whether the disturbance originated in the transformer, or entered from the outside.

To conclude then, the two most important numerical relations, which govern the electrical disturbances in high voltage systems, are:

a. The relation between the maximum current i_0 and the maximum voltage e_0 of the oscillation, standing wave, impulse or travelling wave:

$$\frac{e_0}{i_0} = z_0$$

where:

$$z_0 = \sqrt{\frac{L}{C}}$$

is the natural impedance of the circuit.

b. The transformation ratio of voltages e_1 and e_2, and currents i_1 and i_2, at the transition point between two adjoining circuit sections, of the natural impedances z_1 and z_2 respectively:

$$\frac{e_2}{e_1} = \sqrt{\frac{z_2}{z_1}} = \frac{i_1}{i_2}$$

and from these two relations, very considerable information on the nature, cause and effect of transients can be derived.

"Brown" Gold or "Dark" Gold. M. HANRIOT. (*Compt. rend.*, clii, 138.)—"Dark" or "brown" gold is the name given by the author to the very finely divided gold obtained by the action of an acid on an alloy of gold and silver. When exposed to heat the color changes and it shrinks considerably. The shrinkage is slow and reaches its limit at the end of 5 to 6 hours. The shrinkage of the sheet, when exposed to nitric acid, depends only on the composition of the alloy and not on the temperature. The thickness has no effect, except that the thicker the sheet the longer it must be heated with nitric acid to completely remove the silver.

New American Lathes. ANON. (*Iron Age*, lxxxvii, 546.)—The American Tool Works Co., Cincinnati, O., have introduced two new types of high-duty lathes, said to be the latest and highest developed types, and to surpass in power, range, and convenience any previously designed lathes of similar sizes. Full descriptions and drawings are given in this article, which will repay those interested for its perusal.

ELECTRIC FURNACES.*

BY

CARL HERING, M. E.,

Consulting Electrical Engineer.

(SYNOPSIS.—The paper described the fundamental principles of the design, construction and operation of electric furnaces, their characteristics and idiosyncrasies, the characteristic differences between them and combustion furnaces, their relative advantages and disadvantages, etc., and was illustrated with a large number of lantern slides showing the construction of those in use, accompanied by statistical data concerning their outputs. As the discussion following the paper was confined chiefly to the writer's new type of furnace, additional data concerning it has been included in this abstract, by request.)

THE electric furnace is to-day no longer a laboratory device; it has taken a prominent place in the industries and has become a very important commercial apparatus, its importance growing daily. Not including the very large number of small laboratory furnaces, there are to-day hundreds of large furnaces in use in the industries producing thousands of tons of commercial products daily. In some cases the products are produced better or cheaper than before, while in others important products, which had never before been known or which could not have been produced with other furnaces, are now produced in large quantities.

Among the present uses of the electric furnace may be mentioned the refining of steel, the reduction of iron ores by means of water power, the production of aluminum, silicon, graphite, carborundum, alundum, calcium carbide, other carbides, bisulphide of carbon, ferro alloys, fused jewels, etc.

The electric furnace even promises to affect the wealth of nations. Sweden, one of whose national products for many generations was the famous Swedish iron, has for some time past been losing this important industry owing to the greatly increased cost of charcoal. But owing to the enormous water

* Abstract of a paper presented at the meeting of the Electrical Section held Thursday, April 20, 1911.

powers in that country, and the generous and wise aid of its parental government in developing them, Sweden will now be able to again recover that important national industry by means of the electric furnace, which requires only a fraction of the charcoal that the blast furnace does, and which enables the iron to be converted directly into refined steel of considerably higher money value.

Norway's national industries will no doubt also be affected by the electric furnace. Its barren rocky western coast, unfit for most other purposes, is admirably adapted for electric furnace industries, on account of its numerous easily available and nearly constant water powers located on the immediate coast where the products and raw materials can be cheaply shipped by water, which shipping will probably forever be open to normal competition and beyond the control of railroads, hence can always be relied upon to remain reasonable.

Canada and the states along the Pacific coast, which abound in water powers and mines but have no cheap coal, will no doubt also be greatly benefited by the electric furnace for reducing and refining the metals, provided nature's generous gift of water power will not be allowed to become monopolized by private interests, whose charges for power are governed only by the rule to charge "the highest price that the traffic can bear." The developments of the electric furnace industry will depend greatly on whether or not the governments can keep control of the water powers and regulate the charges. Existing power plants would no doubt find it profitable to encourage the use of their power for furnaces, by offering reasonable and attractive rates, with an assurance of their permanency.

In its general principle, the electric furnace is an extremely simple device, as it merely converts the most available form of energy, namely, electric energy, into the lowest and most degenerate form, heat. Nature tends to do this for us if we give her the opportunity. Hence so far as this conversion of electric energy into heat is concerned, electric furnaces require no skill to design; it is the reverse operation, namely, the conversion of heat into electrical energy, that is difficult and requires the highest skill of the engineer in the designing of boilers, engines and dynamos, each of which itself is the result of a vast amount of study and skill.

The engineering skill required in the design and construction of electric furnaces therefore lies not in the fundamental conversion of energy, but in building them well and efficiently, the latter being of far greater importance than in combustion furnaces in which the cost of a unit of heat is so much less that great economy is not of so much importance. Heat generated electrically costs more per unit of heat, hence to successfully compete with combustion heat it must have other advantages; one of these is that such heat can be applied more directly to the materials, hence with far less waste, and when in addition the furnace is built so as to keep the heat in it as much as possible, the difference in the amount of heat required may become very great, thereby compensating for the higher cost per unit.

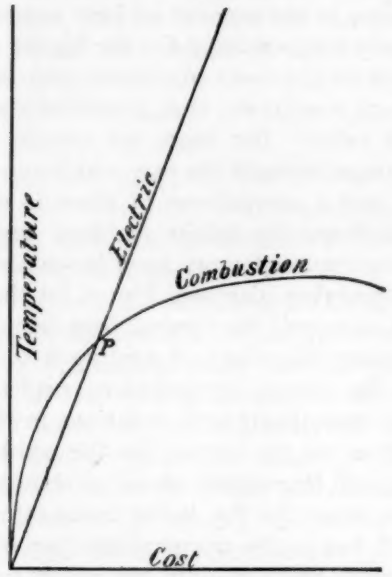
A comparison of the costs of electric and fuel heat depends so largely on local conditions, that a general comparison would not be of much value. But there are certain important characteristic differences between the two which can be compared in a general way, and a comparison of these is quite instructive. It may be best shown by means of those useful tools called "curves," the international short hand language of engineers.

In the accompanying diagram, Fig. 1, let the horizontal distances represent costs and the vertical ones temperatures, and let the curves represent the costs of heating a given body, say a ton of steel, to the various temperatures, neglecting such modifying factors as latent heats and variations in the specific heats. The general shapes of the curves for the combustion heat and the electric heat will be roughly about as shown. For the combustion heat the costs for the lower temperatures will be seen to be quite small, but as the temperatures become high the costs increase very much more rapidly, so much so that the curve finally becomes horizontal and even falls again, hence has a maximum point. Beyond this point the volume of gases in the blast becomes so great that they carry off the heat more rapidly than the fuel can supply it, hence they actually reduce the temperature by chilling the fuel or the gases. A simple example of such a case is blowing out a candle, in which operation the too great volume of air carries off the heat more rapidly than the combustion can supply it, hence it chills the oil and the combustion consequently ceases. In all combustion furnaces the gases must necessarily leave at least at the temperature of the

body which is heated, and generally they leave at a far higher temperature, and all the heat carried off by them is waste, except when it is partially recovered by regenerators. Another reason for such a maximum temperature is the dissociation of the gases, which means that the components cease to combine, hence cease to generate heat.

The corresponding curve for electric heat is roughly a straight inclined line, as shown; in other words, the cost increases at an approximately constant rate, and there is no maximum point, as

FIG. 1.



long as there exists a material to carry the current. The two curves therefore always intersect each other, and at this point P the costs are equal.

It will readily be seen therefore that low temperature heat is in general generated more cheaply by combustion, while for the higher temperature heat it is cheaper to use electricity; also that for temperatures above the point P the cheapest way would be to combine the two, using combustion heat for the lower temperatures, below this point of intersection, that is, for melting or preheating cold charges, and electric heat for the higher tem-

peratures, above the point *P*. This is what is now common practice in the electric steel industry, in which the melting is done by combustion heat, the hot metal being then run into the electric furnace for further treatment. If it were possible to so construct an electric furnace that both kinds of heat can be applied in the same furnace, then the advantages and the economy of this ideal combination could be fully realized. Such a furnace will be described below.

The relations of these two curves will, of course, vary with local conditions, and their shapes will also change somewhat; they should therefore be considered as showing only the general characteristics. Where water power is cheap and fuel expensive, the straight line will be steeper and the other one will rise less steeply and be more flat at the top, while in localities where there is no water power, and where coal is cheap, the curved line will rise more steeply.

The maximum temperature for the combustion curve in commercial furnaces is in the neighborhood of those used in the iron industry, roughly between about 1500° to 1900° C. (2700° to 3400° F.). The maximum for the electric arc furnace with carbon electrodes is their volatilization point, about 3500° to 4000° C. (6000° to 7000° F.), or just about double, hence far greater than necessary for most metallurgical purposes.

The chief advantages of electric furnaces over those of the combustion type are too well known to require more than mention here. They include the neutral atmosphere, that is, the heat is neither oxidizing nor reducing; the possibilities and ease of obtaining the higher temperatures; the rapidity of heating; metallurgical cleanliness (that is, no impurities like ash, sulphur, etc., introduced by the heating process); no losses in waste gases; greater possible economy in the heat losses; the heat may be generated in the material itself (in resistance as distinguished from arc furnaces); the heat may be generated at the bottom instead of at the top, at least in some resistance furnaces; ease, accuracy and reliability of control and regulation; greater uniformity and reliability of product; greater output for a given size of furnace or a smaller furnace for a given output; reduction of labor and sometimes of the plant; incidental advantages such as better castings due to greater fluidity of metal, less waste of metal, etc.

The purpose of furnaces may for convenience be divided into three general groups, although these often overlap. In the first group the chief purpose is merely to melt, vaporize, dry, etc., that is, to merely change the physical state, as for instance in the simple melting furnaces, the steam boiler, the drying furnaces, etc.; this is the chief field for the combustion furnaces.

In the second group the chief purpose is merely to provide a high temperature atmosphere so as to enable certain desired chemical reactions to take place which will take place only at those temperatures; little or no heat is actually consumed in these (except that to raise the cold materials to those temperatures), hence the only heat necessary to provide continuously is that required to supply the losses through the walls, chimney, electrodes, doors, etc., hence in these the reduction of the losses is of prime importance; to this group belong those for refining steel, making carborundum and graphite, glazing pottery, baking stonewares, the kitchen stove, etc.

In the third group the chief function is to store up chemical energy in the product, that is, to produce endothermic chemical reactions; in these, energy must be supplied not only to provide for a high temperature atmosphere, as in the second group, but also to provide that energy which is being stored chemically in the product and which in some cases may be the greater amount; the energy so stored cannot be counted upon to produce heat for raising or maintaining temperatures. To this group belong the furnaces for the reduction of metals from their ores, like iron, aluminum, zinc, silicon, etc., the production of calcium carbide, bisulphide of carbon, etc. All such elements or compounds may subsequently be used (generally by burning) to generate heat, light or other forms of energy (such as the electric energy from zinc in batteries), and it is the energy thus obtained that was stored in them in the furnace in which they were originally produced. In the designing of such furnaces it is therefore very important to know whether the product is endothermic, and to what extent, for unless the furnace is made to supply the energy which is to be stored in the compound it will be a failure.

As temperatures rise, the chemical affinities or bonds between the various elements become weaker and weaker until finally they cease to exist; when water, for instance, is heated to a high enough temperature, the oxygen and hydrogen composing it will

exist free and uncombined as elements, as their bond has been broken; the water is then said to have been dissociated. When our earth was a mass of molten and gaseous material at extremely high temperatures, the various elements composing it were presumably in this uncombined form or at least in loosely combined compounds. As it cooled, the elements combined or mated in various forms, depending upon chance, that is, on the local supply. These bonds tightened as the earth cooled, and with the aid, later on, of the chemistry of plant life, the rock, water, and air composing the earth's outer envelope, were formed.

The electric arc furnace, apparently for the first time during those millions of years, enables us now to reproduce the extremely hight temperatures of those earlier periods, hence to again break most and probably all of those chemical bonds, that is, to unmate the elements, and by then providing proper artificial surroundings we are enabled to compel them to recombine or remate differently or remain uncombined, in accordance with our desires, hence improving on nature's process which depended upon chance. Iron, aluminum, silicon, zinc, lead, and other reduced metals, which nature has not given us as metals in the rock, are produced in this way, though not necessarily always in the electric furnace.

In general, electric furnaces may for convenience be divided into two types called resistance and arc furnaces, although the distinction is somewhat artificial. In the resistance type the heat is generated by passing the electric current through a solid or liquid conductor, the resistance of which causes the electric energy to be converted into heat. In the arc furnaces this resisting conductor is a gas, namely, the vapor of the electrode material, and as gases ordinarily have a very high specific resistance an arc furnace may be said to be a resistance furnace in which a very high resistance capable of carrying a very large current is confined in a very small space, hence the high temperatures.

In the arc the current forms its own conductor by vaporizing the end of the electrode. Hence its temperature is always that of the boiling point of the electrode material; if it were momentarily any higher it would vaporize more material and this would reduce it again. This temperature therefore seems to be a fixed one, but it is generally far higher than what is wanted for most operations. It seems to be the limit which can be reached in

an arc furnace, but being almost always so much higher than is needed, it seldom if ever acts as a limitation to a process.

This extremely high temperature is the chief advantage of the arc furnace; it is reached instantaneously in the arc itself.

By far the greater part of the total heat is believed to be generated in the arc and at the end of the electrode, only a smaller part being set free in the furnace product itself which generally forms the other electrode; hence the larger part of the heat has to be transmitted to the material by radiation and by whatever convection there may be due to the hot vapors coming into contact with the material; in both these mehods of heat transmission, however, the speed of transmission increases with the temperature of the generated heat, and this speed is a very important element in furnace design. This is the redeeming feature in that high temperature, as in other respects it is very objectionable, because it increases the losses very greatly; in an ideal furnace the temperature should not be higher than needed, on account of this increased loss. In some cases this locally high temperature of the arc produces injurious results on the product and is therefore objectionable, and sometimes even fatal; in melting brass, for instance, there is danger in volatilizing some of the zinc.

The energy consumed in vaporizing the electrodes cannot, of course, appear as heat also, hence it represents a constant loss unless it is again recovered by subsequent condensation or burning, in which case, however, it becomes useful only if the recovered energy actually reaches the product.

As carbon or graphite electrodes are usually used in arc furnaces, the vapor is that of carbon, which presumably acts reducingly, and is known to tend to form carbides with the materials. The advantages of metallic electrodes to reduce the electrode losses cannot be made use of in arc furnaces. Another disadvantage is that in heating liquids with the arc (and everything seems to melt in the arc), the heating must necessarily be from the top only, hence the transmission of the heat from the lower terminal of the arc to the rest of the material must be by the slow process of conduction, except in so far as agitation may distribute it by convection. It is evidently wrong in principle to heat a liquid from the top, as it is then necessarily a slow process; this is therefore an intrinsic disadvantage of the arc

furnace, but is partly compensated by the extremely high temperatures which tend to hasten such transmission of heat. The mechanism required for regulation, the constant attention required by such regulators, and the breaking off of the ends of the electrodes, are further objectionable features of arc furnaces. These objectionable and undesirable features are, however, often outweighed by the advantages, as such arc furnaces have become very important in the industries and have produced excellent and valuable results.

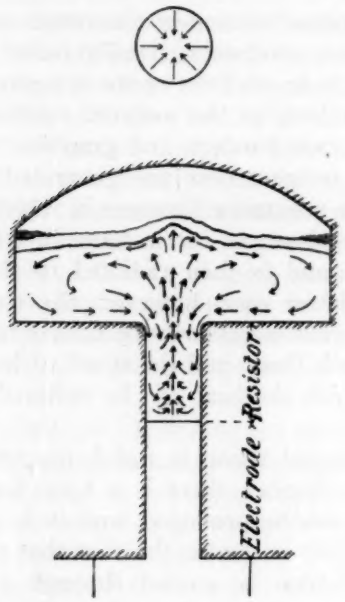
Resistance furnaces have other advantages and disadvantages. When the resistance conductor, usually called the resistor, is a solid, there seems to be no limit to the temperatures that can be produced in it, as long as the material remains a solid. This is the case in the carborundum and graphite furnaces in which exceedingly high temperatures are generated. This seems to apply also to those resistance furnaces in which the heat is generated in a solid resistor, as for instance in a bed of coke or in blocks of carbon, and is then radiated to the material to be treated. In the latter case, however, the temperature of the furnace products must necessarily be considerably lower or else no heat would reach them, and the speed of heating depends on the rapidity at which the heat can be radiated across the intervening space.

When the material through which the current passes is a liquid in an open channel, there is a very decided limit to the temperature that can be produced, and it is sometimes a seriously low one. This is due to the fact that there is a limit to the current which can be passed through a horizontal open channel containing a liquid, for when the current reaches a certain amount, depending on the cross section and shape of the column and on the specific gravity of the liquid, the column is suddenly contracted by electromagnetic forces until it breaks the circuit; this produces rapid interruptions of the current, which prevent a further increase of current and are fatal to the operation of the furnace. This curious electromagnetic phenomenon was described by the writer some years ago [1] and was named the "pinch phenomenon," by which it is now generally known.

[1] "A Practical Limitation of Resistance Furnaces: The 'Pinch' Phenomenon," *Trans. Amer. Electrochem. Soc.*, 1907, vol. xi, p. 329. "The Working Limit in Electrical Furnaces Due to the 'Pinch' Phenomenon," *Trans. Amer. Electrochem. Soc.*, 1909, vol. xv, p. 255.

Were it not for this phenomenon, the resistance furnace would approach the ideal in some respects for liquids because the heat is generated in the material itself, as it is in the graphite furnaces, hence the utilization of the heat is complete, that is, 100 per cent., which means that the only losses of heat are those from the charge, as distinguished from those which never reach the charge.

FIG. 2.



In an endeavor to overcome this serious limit in liquid resistance furnaces imposed by this pinch effect, the writer has devised a form of furnace in which this obstructing force not only cannot sever the conductor, but is even made to produce a very valuable property, namely, rapid circulation of the liquid in the resistor and in the hearth. The principle is shown in Fig. 2.

If a column of a liquid conductor is confined in a vertical cylindrical hole in the bottom of the hearth, opening into the body of the liquid and closed at the bottom by means of the electrode, and if a current be then passed lengthwise through it, the effect of the pinch phenomenon will be to contract this column

toward its central axis; the liquid will therefore tend to move radially from the circumference to the centre, as shown in the small circle at the top of Fig. 2. These forces in turn, by hydraulic action, then produce an axial force which will force the liquid upward and out of the column, while at the same time the suction will draw in fresh liquid around the circumference, producing a circulation about as shown by the arrows in the lower figure. This peculiar phenomenon acts like a valveless pump, forcing the liquid upward and producing a small fountain.

These liquid columns or resistors, of which there are two, one for each electrode, are so proportioned that the whole heat for the furnace is generated in them, and the diameter and current are so proportioned that the pinching force is sufficient to produce the desired circulation. Each particle of the liquid in turn enters the resistor, where it is immediately highly heated and ejected, being in the resistor only about a second. The freshly heated metal is forced to the top where, in the case of steel refining, it comes into intimate contact with the blanket of slag where the chemical action which constitutes the refining, takes place. The cooler material at the bottom flows into the resistor and is in turn heated and ejected. For three-phase current there are three resistors and electrodes.

Among the advantages claimed are: quick action, which means a large output per day and less standby losses per ton; a very large effective surface of contact with the slag, as this surface is continually being renewed, hence rapid refining action; rapid purification of suspended matter (slag, gases, oxides, etc.), as this is freed as the liquid reaches the top and deposits such matter in the slag; heating from the bottom, which is the more rational method; practically perfect homogeneity, on account of the rapid and systematic circulation; possibility of making the hearth deep and narrow instead of shallow and broad, hence reducing the rather large losses through the walls; reduction of the temperature to the lowest necessary for the chemical reaction, that is, no excess of temperature with its attending increase of the losses; the possibility of using metal electrodes, which are much more economical in losses of power than those of carbon or graphite; no consumption of electrodes, which is such an important item of cost in arc furnaces; no contamination of the material with that of the electrode, as the latter is made of the same material; no continual adjustment of the electrodes as

in arc furnaces, and therefore no expensive machinery for doing it; ease and nicety of regulation by merely varying the voltage of the transformer; capability of adding fuel heat at the top in the form of gases for preheating the cold material and producing the low temperature heat, thereby obtaining increased economy, as was described above; as the current is generated in a separate transformer, there is no reduction in the power factor; the larger the furnace the better does the principle apply; the possibility of applying it to exsting open hearth furnaces; simplicity and compactness of construction; ease of operation; ease of making repairs of the tubes; etc.

Figs. 3 and 4 show in its outlines only, a small, crude form of crucible tilting furnace of this type. The sketches are self

FIG. 3.

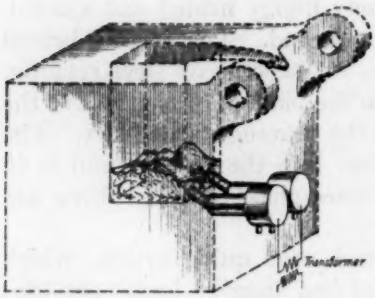
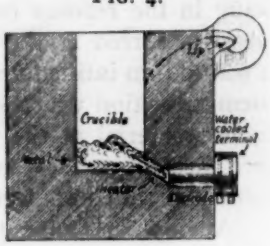


FIG. 4.



explanatory. It is shown as tilting around the lip, so as to pour directly into moulds. It is started either with a small liquid charge, just enough to connect the ends of the electrodes when tilted; or by melting a small charge in it with an oil flame; or by a casting made to fit the bottom and then melted electrically; a small charge is always left in it and this can readily be melted with the current when it may have become frozen.

Figs. 5 and 6 show how these resistors or squirting tubes and their electrodes may be applied to the usual type of tilting furnace. Fig. 5 is a vertical section through one of the two electrodes and tubes; Fig. 6 shows a top view of a horizontal section at about the level of the doors.

Another form of liquid resistance furnace, which was originally intended to dispense entirely with the electrodes and their troubles, is known as the induction furnace. The liquid is in a narrow circular channel which forms the secondary circuit of a

transformer, hence the current is induced in it without the necessity of electrodes. It is so well known, having been invented about twenty-five years ago, that a further description need not be given here. (Numerous forms of it were shown among the lantern slides.) It has come into use in Germany chiefly for steel refining, and its introduction seems to be increasing; it is not yet in use to any extent in this country. It posses the advantages which liquid resistor furnaces have over arc furnaces, as mentioned above. It is started with a liquid charge or a ring of cold metal. It is significant that in its most successful form electrodes are introduced to heat a larger open part of the bath necessary for operating the slags and for adding cold scrap or

FIG. 5.

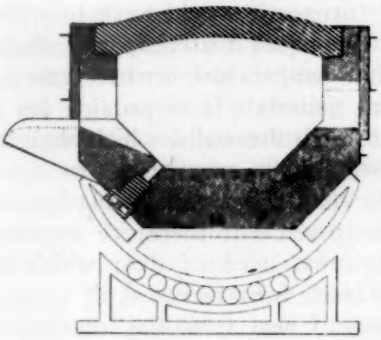
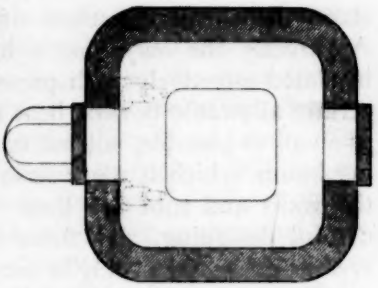


FIG. 6.



pigs. Its disadvantage, besides its cost, is that the frequency of the alternating current must be quite low or else the power factor becomes very low. This means larger machinery, though not necessarily more power. This disadvantage increases with the size of the furnace. The pinch effect would probably also limit the rapidity of action, by limiting the current which can be passed through the metal. It is difficult to provide for good heat insulation on account of the very large surface of metal exposed to the walls.

One of the chief features in the work of the engineer, in the designing of electric furnaces, is the reduction of the losses of heat, that is, the increase of the heat efficiency of the furnace; electric heat being much more expensive than heat from fuel, the only way it can be expected to compete successfully, as far as the cost of the heat is concerned, is by the best possible utiliza-

tion of the energy; it is possible to control the losses to a far greater degree in electric than in combustion furnaces. The practice in the heat insulation of combustion furnaces would be quite inadequate for well built electric furnaces.

The reduction of the heat losses in electric furnaces, which have no chimney losses, involves the flow of heat through solids, a subject which until recently has not been given the attention which its importance demands. Heat insulation is rendered more difficult by the fact that nature has given us no virtually perfect heat insulators like those for electricity, and that even if they existed they could not be used for high temperature insulation on the outside of a furnace, as the whole furnace wall would then assume the full inside temperature, like in cases of over-insulation, which few known refractory materials would stand; and if used on the inside of a furnace it would have to withstand the chemical actions of the liquid materials and slags. Apparently the only way a high temperature furnace can be insulated effectively with present materials is to provide for a certain allowable flow of heat through the walls, which shall be as small as possible, but not so small as to run the risk of over-insulation, which is more serious than insufficient insulation, as the walls and roof are then destroyed. It therefore requires careful designing, and there is great need of data which at present exists either only in very crude form or not at all.

There are two kinds of losses of heat from the interior of an electric furnace, namely, those through the walls and through the electrodes, which are subject to the control of the designer, assuming, of course, that the doors and openings of other kinds are made as few and small as possible. A few years ago the writer made analytical studies of these two sources of losses, some of the conclusions of which were quite surprising, showing that former practice had been in some respects far from correct. The chief results are briefly as follows:

The usual formulas used for calculating the thermal resistance of such bodies as the walls of furnaces were found to be very greatly in error, as much as 100 per cent. and over, for thick walls. In general, for a flaring conductor, like one of the thick walls of a rectangular furnace, the proper mean cross section is not the arithmetic mean between those at the two ends, but the geometric mean, that is, the square root of their product.

Using the strictly correct formulas, it was found that the losses diminished very rapidly at first as the walls are increased in thickness, but that after the thickness has been increased to about one-half or three-fourths of the inside diameter, any further improvement in reducing the losses becomes small. The space in the inside of a furnace should be as small as possible to hold the charge, as the losses for the same charge increase rapidly with an increased inside surface. The losses in a large furnace can be made far smaller relatively to the charge than in smaller ones; hence it is considerably better to use one large furnace than two smaller ones of half the capacity.[2]

Concerning the losses in and through the electrodes, the problem was far more involved, and former practice was in some respects found to have been radically wrong. An electrode naturally should be a good electrical conductor in order to reduce the resistance losses. But it then also is a good heat conductor and therefore will tend to abstract considerable heat from the charge in the inside, thereby chilling it. Increasing its cross section decreases one of these losses and increases the other, thereby complicating matters. The results of the analysis are briefly that, by so proportioning an electrode that the current in it will heat its inner end to the furnace temperature, the total combined losses will be the least possible, and the electrode will at the same time abstract no heat from the charge; it will then in effect act as a perfect heat insulator, better even than the walls, as far as chilling the product is concerned.

Another result was that our former practice to base the size of electrodes on certain allowable current densities was found to be entirely wrong. Still another unexpected and surprising result was that graphite with its higher heat conductivity was more economical in size and losses than carbon, and that the metals were far better than either, the best electrode material being copper, quite the contrary to what would have been supposed. The accompanying illustration, Fig. 7, taken from one of the writer's papers, shows the relative sizes and losses when the electrodes for the same furnace are made of different materials.

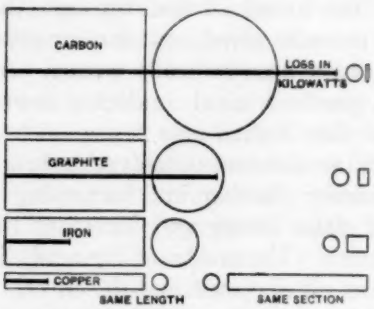
---

[2] For further deductions see the paper by the writer on "Heat Conductances Through Walls of Furnaces," *Trans. Amer. Electrochem. Soc.*, 1908, vol. xiv, p. 215.

It is a good illustration of the commercial value of an analytical research. As the physical constants for determining electrodes did not exist, the writer had to determine them by means of tests made under electrode conditions, whereby certain troublesome factors in the theoretical analysis become eliminated. The complete analysis, description of the tests, and the data for the calculation of electrodes are given in the original papers.[3]

In view of an article on "Simplicity in the Measures of Physical Quantities," published in the February issue of this

FIG. 7.



Comparison of sizes and losses.

JOURNAL, p. 129, in which the writer showed the advantages which would be gained by simplifying our units of measurement, it may be of interest to call attention here to the fact that such calculations of the flow of heat as those just referred to above become very greatly simplified, and in fact ideally simple, if the proper units are chosen. If in the present cases thermal resistances are used instead of conductivities, and if a new unit of resistance is adopted called the thermal ohm, calculations of the flow of heat, or of heat currents, become quite analogous and

[3] "Laws of Electrode Losses in Electric Furnaces," *Trans. Amer. Electrochem. Soc.*, 1909, vol. xvi, p. 265. "A New Method of Measuring Mean Thermal and Electrical Conductivities of Furnace Electrodes," *Trans. Amer. Electrochem. Soc.*, 1909, vol. xvi, p. 317. "The Proportioning of Electrodes for Furnaces," *Proc. Amer. Inst. Elec. Eng.*, March 31, 1910. "Determination of the Constants of Materials for Furnace Electrodes," *Trans. Amer. Electrochem. Soc.*, 1910, vol. xvii, p. 151. "Empirical Laws of Furnace Electrodes," *Trans. Amer. Electrochem. Soc.*, 1910, vol. xvii, p. 171. "The Design of Furnace Electrodes," *Elec. World*, June 16, 1910, vol. lv, p. 1598.

just as simple as those for electrical currents, as the coefficients are then unity.

This was explained in a recent article.[4] Briefly, if the currents of heat are represented in watts, instead of calories per second (which in itself saves a double transformation of units), the temperature in centigrade degrees, and the thermal resistances in those new units called thermal ohms, then, analogously to Ohm's law,

$$\text{watts} = \frac{\text{degrees}}{\text{thermal ohms}}$$

which is an ideally simple calculation. And if the specific thermal resistances of the various heat insulating materials are given in terms of these thermal ohms, which transformation is made once for all in preparing the tables, then as in electrical calculations, if r is this specific resistance of the material, R the total thermal resistance of a furnace wall or an electrode, S the cross-section of it perpendicular to the flow, and L the length parallel to the flow, then

$$R = \frac{rL}{S}$$

which is correct for centimetres or inches, provided the same units are used consistently throughout.

In conclusion, the following statistical data concerning existing commercial furnaces may be of interest.

The carborundum furnaces are 30 feet long and 12 feet wide, require 1600 kilowatts at 20,000 amperes, 80 volts and 25 cycles, have an estimated temperature of 2300° C., and yield 15,000 pounds of crystalline carborundum at each run.

The graphite furnaces are just like these and yield about 17 tons per day, the output last year being 12,000,000 pounds of a purity up to 99.9 per cent.; the temperature is estimated to be about 4000° C.

The silicon furnaces are double electrode arc furnaces 10 feet wide and 16 feet long, and require about 1000 kilowatts.

The bisulphide of carbon furnace is 41 feet high, 16 feet in diameter, requires about 400 horsepower, and yields about 6 tons

[4] "Thermal Resistance and Conductance; the Thermal Ohm and Thermal Mho," *Met. and Chem. Eng.*, Jan., 1911, vol. ix, p. 13.

per day; it is a three-phase arc furnace with three electrodes; the temperature is said to be about 1000 to 1500° C. Although built in the last century (1898) when it was probably by far the largest electric furnace ever constructed, it is running to-day as it was then. It is probably the most efficient electric furnace in use, as far as the economy of heat is concerned. It revolutionized the manufacture of bisulphide of carbon. The materials charged are sulphur and charcoal, and the product is a vapor which is subsequently condensed.

For the melting and refining of steel there seem to be at present nearly 100 arc furnaces in use mostly in France and Germany, although the few in this country include the largest ones. They are chiefly of the Heroult and the Girod types. They are mostly of about 300 to 800 kilowatts, and are for charges of 2 to 5 tons; the largest ones are in South Chicago and Worcester, having a capacity of 15 tons and requiring about 2000 kilowatts. There are also several ore reduction arc furnaces in use and under construction on the Pacific Coast, and in Domnarfvet, Sweden, the latter producing 2500 tons per year and requiring 400 kilowatts, or about 6500 pounds of pig-iron per horsepower per year. In Norway two furnaces are under construction, each for 7500 tons annually, requiring 1850 kilowatts.

The Government of Sweden is about to make available 600,000 horsepower, a large part of which will be used for reducing iron. Electric furnace reduction of iron is said to save about two-thirds of the carbon, only one ton of charcoal being used instead of three, per ton of iron. The escaping gas is three times richer as it contains no nitrogen, and is only one-eighth in amount, hence correspondingly less heat is carried off by it. Finely powdered ore can be used without briquetting; there is less labor cost and less cost of erection.

Of the induction furnaces there are between 30 and 40 in operation, mostly in Germany. They are mostly of 200 to 500 kilowatts; maximum 750. The charges are from 1½ to 5 tons; maximum 8½ tons. In some cases the material is charged hot and in others cold.

Among the pioneers in this country to whom the present commercial furnaces are due may be mentioned Acheson, Taylor, Hall, Tone, and Colby; and abroad, Heroult, Girod, Keller, Kjellin, and Stassano.

A NULL METHOD FOR MEASURING RELATIVE INTENSITIES OF RÖNTGEN RAYS.

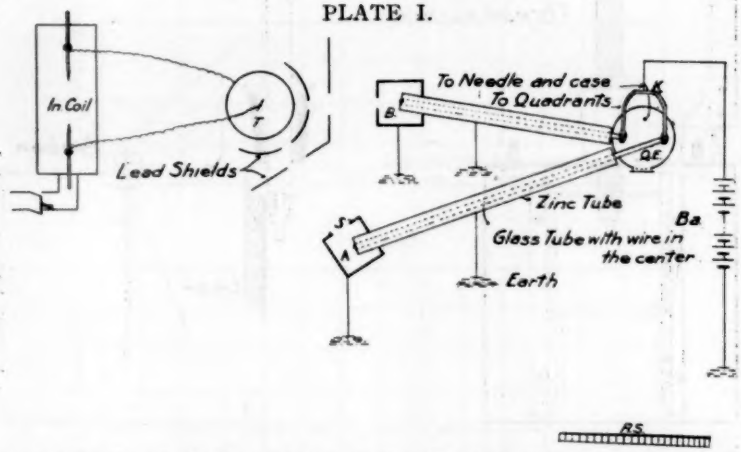
BY

Prof. W. R. HAM, L. J. LASSALLE, AND OSCAR F. SMITH,

Department of Physics, Pennsylvania State College.

THE method of measuring relative intensities of radiation of Röntgen rays by the discharge of electroscopes requires considerable time, not only in the actual reading, but also in the arrangement of the apparatus so as to eliminate as far as possible any leak in the systems. Furthermore, the readings extend

PLATE I.



In. coil, induction coil; *T*, X-ray tube; *S*, shutter; *B* and *A*, electroscopes; *QE*, quadrant electrometer; *K*, hinge switch; *Ba*, dry cells, 450 volts; *R S*, reading scale.

over such long periods of time that errors may be introduced owing to changes in conditions, especially changes in potentials. Those who have had experience with this method have felt the need of greater accuracy and speed.

The work described in this paper investigates the two following hypotheses:

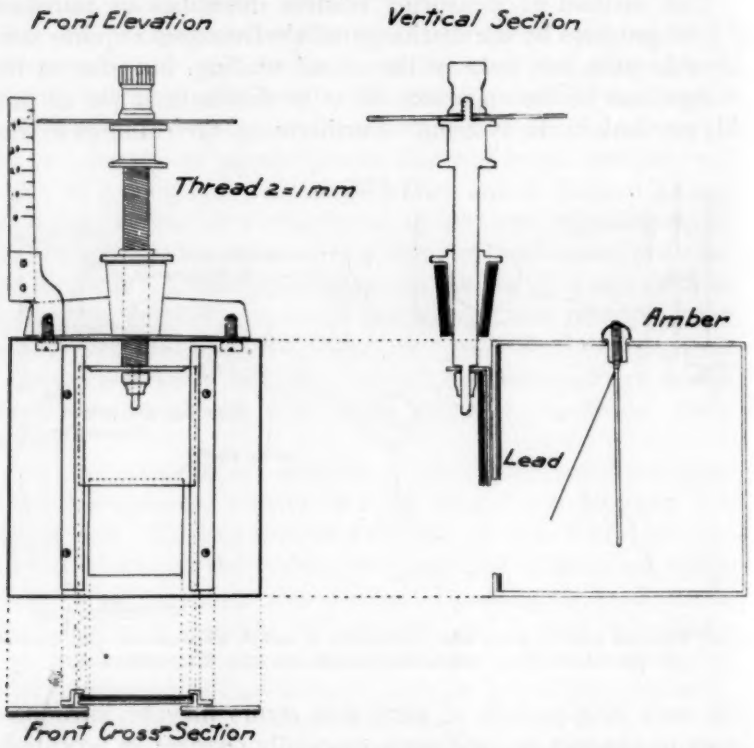
1. *The amount of ionization caused in an ionization chamber by rays emanating from the target of an X-ray tube varies inversely as the square of the distance of the chamber from the target, neglecting absorption.*

2. *The amount of ionization caused in an ionization chamber by Röntgen or other rays having ionizing power varies directly as the area of the opening allowing the rays to enter the chamber.*

Both hypotheses assume a point source.

To these hypotheses may be added that the amount of ionization is proportional to the fall of the leaf in an electroscope (used as an ionization chamber in this case), provided the fall

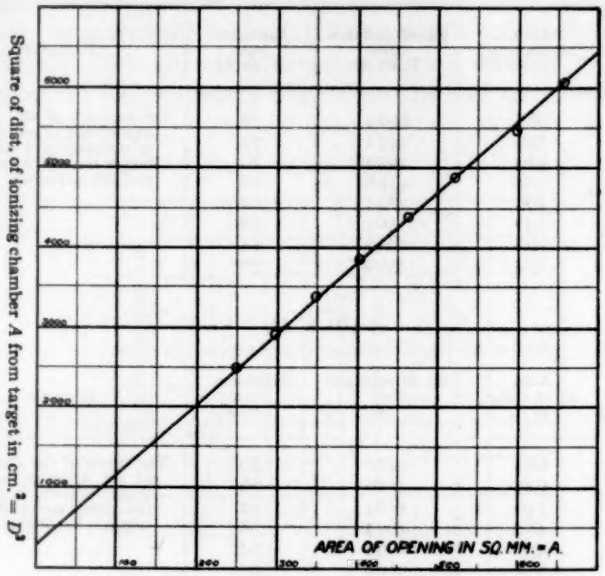
PLATE II.



is small in comparison with the total deflection and provided change in capacity is negligible.

The arrangement of apparatus for testing this method is shown in Plate I. Two similar electroscopes, arranged symmetrically with respect to the normal to the target of a Crookes' tube, served as ionization chambers. Chamber *A* was placed on a track so that its distance from the target could be varied at will, while chamber *B* remained at a fixed distance. Chamber *A*

PLOT I.



PLOT II.

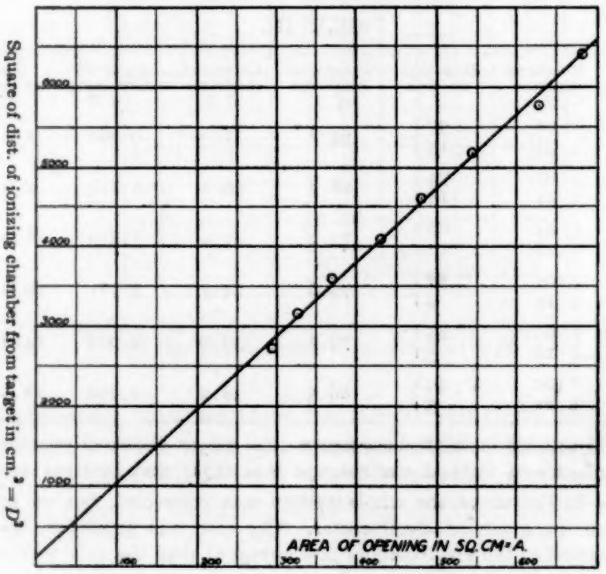


TABLE I.

Reading No.	Area of opening in A.	Sq. of distance from T. to A.	Distance from T. to A.	Remarks
1	666	6084	78	On account of the coef. of absorption of air, the area of opening in A has to be larger than it would be if this did not enter.
2	598	5476	74	
3	520	4900	70	
4	458	4356	66	
5	402	3844	62	
6	350	3364	58	
7	298	2916	54	
8	252	2500	50	

TABLE II.

Reading No.	Area of opening in A.	Sq. of distance from T. to A.	Distance from T. to A.	Remarks
1	682	6400	80	The result of the absorption of air entering, as mentioned above, is to bend the curve away from the origin. See Plots.
2	628	5776	76	
3	546	5184	72	
4	484	4624	68	
5	430	4096	64	
6	368	3600	60	
7	328	3136	36	
8	294	2704	52	

TABLE III.

Time in secs.	Readings electros A.	Readings electros B.	Corrected discharge of A.	Corrected discharge of B.	Ratio of discharges $A \div B$	Depth of opening in A.
47	94 33	90 15	54.8	71.6	0.762	2.0 mm.
32	97 24	74 15	68.8	56.8	1.211	4.0 mm.
24	94 18	60 10	72.2	47.9	1.509	6.0 mm.
18	100 18	55 9	79.6	44.7	1.781	10.0 mm.
13.2	99 18	45 5	79.3	39.0	2.029	14.0 mm.
11	100 22	44 5	86.5	38.2	2.266	18.0 mm.

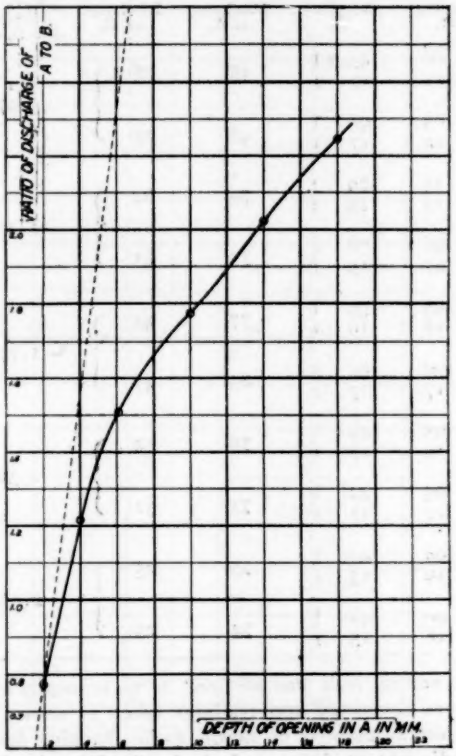
Natural rate of leak of electroscope $A = 0.1317$ divisions per sec.

Natural rate of leak of electroscope $B = 0.0717$ divisions per sec.

NOTE.—In the above the whole system was connected, but no attention was paid to the quadrant electrometer. The case was grounded, the quadrants connected to the electroscopes and charged; then the tube was run and the readings of the electroscopes taken.

was also provided with a shutter as shown in Plate II, which would measure depths to .005 millimetre, and as the area is directly proportional to the depth this depth was used, in plotting, as areas. Both chambers were connected directly to the quadrants of an electrometer; thus when the fall of potential in the

PLOT III.



Readings with ionizing chambers connected to quadrant electrom, with case grounded and quadrants charged to 450 volts.

two chambers was the same the needle remained at rest. These connections were made by means of fine wire enclosed in a glass tube, and this in turn was surrounded by a grounded zinc pipe, in order to do away with any changes in the capacity of the system.

By placing A at a fixed distance from the target and varying the openings in its face until the ionizing effect in the two chambers was balanced, as shown by the electrometer needle, a series of readings were taken, keeping the opening in B constant.

TABLE IV.

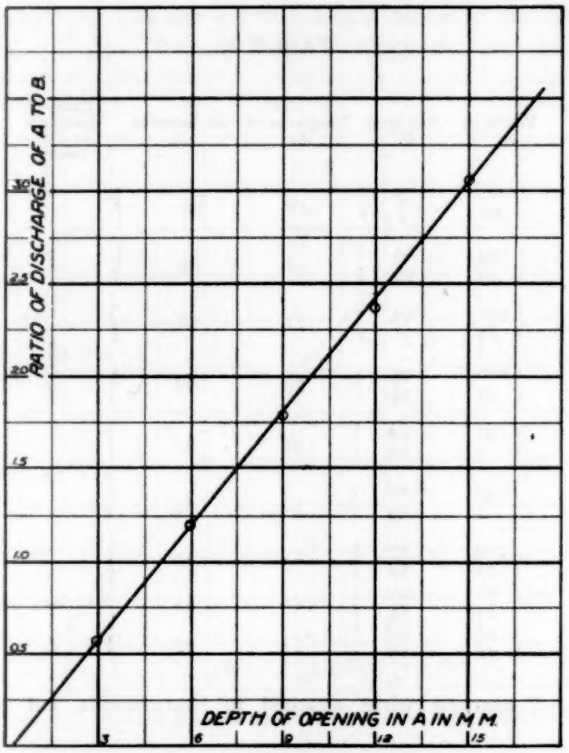
Time in secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.	Ratio of discharge $A \div B$, mean	Depth of opening in A.
12	66 21	95.5 17	45	78.5	0.573	3.0 mm.
12	65 22	96 17	43	75		
6	88 13	79 17	75	62	1.200	6.0 mm.
6	96 21	78 15	75	63		
4	95 18	59 16	77	43	1.778	9.0 mm.
4	100 17	64 17	83	47		
3	95 19	49 17	76	32	2.365	12.0 mm.
3	95 22	42 11	73	31		
2.4	94 19	40 15	75	25	2.980	15.0 mm.
2.4	90 18	40 15	74	25		

NOTE.—The natural leak was so small as to be negligible. The electroscopes alone were connected and readings taken as shown above. This is the ideal condition, as there is no needle to be changing the capacity of the system and no adjacent quadrants to leak. In Plot IV and in Plot V the curves pass through the origin. In the other cases shown the conditions are not ideal, therefore the results cannot be ideal. However, as is pointed out later, in the actual use of this method the conditions are ideal.

Table I shows the data thus taken, and if the two hypotheses are correct, the graph, using areas of opening in A as abscissas and the squares of distances of A from the target as ordinates, should be a straight line passing through the origin. Plot I does

not quite fulfil this condition, but the difficulty was evidently due in part to the fact that some of the rays which entered the ionizing chamber came from the glass instead of the target. For, by shielding the tube with thick lead sheets, openings in which

PLOT IV.



Readings with everything but ground disconnected from ionizing chamber.

permitted only rays coming directly from the target to pass, most of the difficulty was overcome.

However, Table II and Plot II still show a tendency to turn away from the origin in a clockwise direction. This can be explained by the absorption of the air increasing with the distance of *A* from the target and thus reducing the intensity of the rays. Consequently, the opening in *A* for a given distance would have to be larger in order to balance with *B* than other-

wise. For this reason we must modify hypothesis I by adding the clause: *provided the rays are travelling through a medium which exerts no appreciable absorption upon them.*

Thus far we have only shown the two hypotheses to be consistent with each other. It remains to be shown that they do not both involve the same errors and are consistent with the electro-

TABLE V.

Time secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.	Ratio of discharge A. ÷ B., mean.	Depth of opening in A.
35	96 56	75 7	38	67	0.57	3.0 mm.
35	99 59	86 20	38	65		
35	100 27	92 31	71	60	1.16	6.0 mm.
35	100 19	94 24	79	69		
25	97 0	74 16	95	57	1.73	9.0 mm.
25	98 1	88 34	95	53		
15	100 15	87 52	84	35	2.24	12.0 mm.
15	98 21	91 58	76	33		
15	98 16	90 53	71	37		

NOTE.—Connecting wires attached to electroscopes, but electrometer left out.

Natural rate of leak of electroscope $A = 0.063$ divisions per sec.
Natural rate of leak of electroscope $B = 0.023$ divisions per sec.

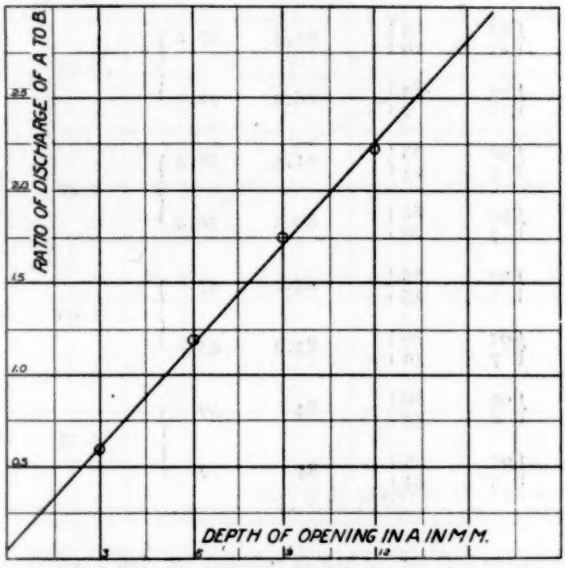
scope method. To do this, the method founded on the second hypothesis was checked by means of the discharge of electroscopes.

Micrometer microscopes were set up to take the ratios of discharge of the ionization chambers. Then by varying the opening in A a set of readings was taken as shown in Table III,

Plot III. As the opening in B was kept constant the ratio of discharge of A to the discharge of B should vary directly as the area, or as the depth of opening of A. The results do not show this law, but as will be seen later the trouble was evidently due to leakage.

To find this trouble the ionization chambers were disconnected from everything but the ground and a series of readings taken as before. Table IV and Plot IV show the law of variation

PLOT V.



Readings with QE disconnected, but with all other connections intact.

to be expected, *i.e.*, rate of discharge varies directly as the depth of opening of A.

Now the connecting tubes between the chambers and the electrometer were attached and another series of readings taken. The results shown in Table V and Plot V still conform with our reasoning. Therefore the trouble was not here.

There was but one thing remaining to be connected, namely, the electrometer. Hence the trouble must be here. The needle was first taken out and then the electrometer was connected and readings taken as before. Table VI and Plot VI, the results

of this arrangement, do not fulfil the requirements. The nature of this inconsistency led to the belief that the trouble was due to a leak between quadrants. In order to lessen the chance of leak the opposite quadrants were disconnected, leaving only one quadrant on each ionization chamber. The data with this arrange-

TABLE VI.

Time in secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.,	Ratio of discharge $A. + B.$, mean.	Depth of opening in A.
40	92 23	85 18	61.4	67.2	0.93	3.0 mm.
40	93 18	84 7	68.4	72.2		
30	92 5	85 23	81.3	58.4	1.48	6.0 mm.
30	93 7	86 26	80.3	56.4		
22	93 5	85 35	84.2	47.6	1.80	9.0 mm.
22	94 7	86 38	83.2	45.6		
18	95 8	86 45	84	39	2.15	12.0 mm.
18	92 5	85 44	84	39		

Natural rate of leak for 1st half of readings for $A = 0.19$ divisions per sec.
Natural rate of leak for 2nd half of readings for $A = 0.17$ divisions per sec.
Natural rate of leak for 1st half for $B = 0.12$ divisions per sec.
Natural rate of leak for 2nd half for $B = 0.11$ divisions per sec.

NOTE.—The needle was taken out and the electrometer connected. The curve does not pass through the origin and is not a straight line. The conditions are not ideal, as the quadrants are not at the same potential and the needle is not steady.

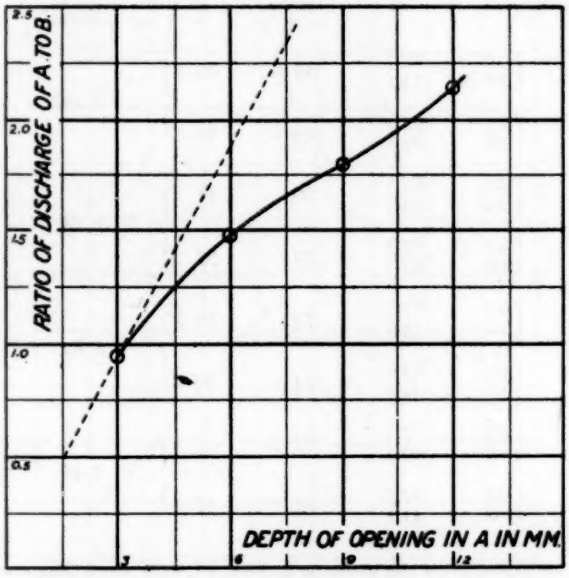
ment was consistent with the theory as appears from Table VII and Plot VII.

This seemed to locate the trouble as a leak from quadrant to quadrant, so the silk insulated wires which had connected the

opposite quadrants were replaced by bare wires and the data for Table VIII and Plot VIII was taken. Evidently these results satisfy the theory.

The needle was now replaced and anchored in a fixed position so as to eliminate any chance of a change in the capacity of the systems due to a change in the position of the needle. The data of Table IX and Plot IX taken under these con-

PLOT VI.



Readings with both sets of quadrants connected, needle still out.

ditions still show some remaining difficulty although the plot is a straight line. However, it seemed probable that the remaining difficulty was such as to disappear under conditions which must exist in the actual use of the method. To test this reasoning a set of readings was taken under the ideal conditions of actual use, *i.e.*, by balancing the ionizing effect for each reading.

Since this is a null method, the quadrants were at the same potential and the needle in a fixed position when the area of opening was taken. Therefore, there was no tendency to leak from quadrant to quadrant and no change of capacity due to

changes in the position of the needle. Furthermore, to do away with any chance of a leak to the ground, the case, the needle, and the quadrants were all charged to the same potential. The case and needle were connected to the battery throughout the test, thus causing a slight leak. However, this leak was deter-

TABLE VII.

Time in secs.	Readings *A*.	Readings *B*.	Discharge of *A*.	Discharge of *B*.	Ratio of discharge *A*.÷ *B*., mean.	Depth of opening in *A*.
40	93 38	87 13	49.0	69.3	0.707	3.0 mm.
40	93 38	87 13	49.0	69.3		
30	94 24	87 33	66	51	1.28	6.0 mm
	92 16	87 27	72	57		
30 22	95 20	87 45	72	39.7	1.82	9.0 mm.
	94 17	87 44	74	40.7		
22 17	95 5	87 49	87.7	36.3	2.46	12.0 mm.
17	94 6	87 51	85.7	34.3		

NOTE.—Connections the same as in Plot VI, excepting that one quadrant was connected to *A* and one to *B*. This tended to keep the leak from quadrant to quadrant down; the case was still grounded, however, giving an opportunity for a leak.

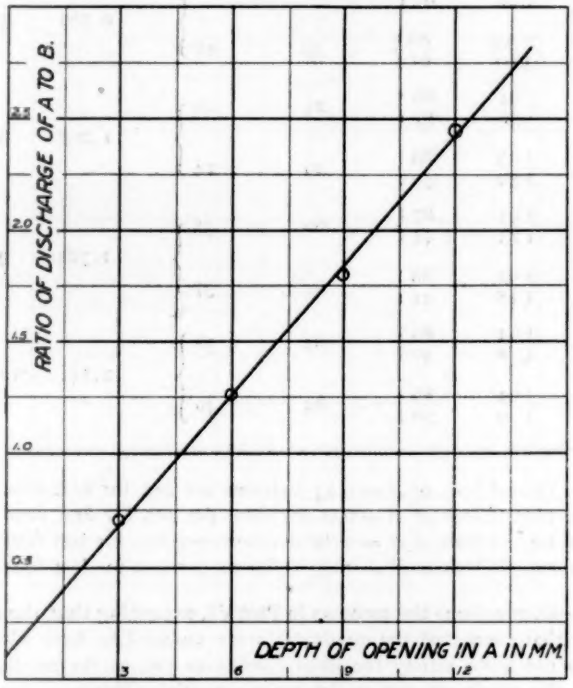
Natural rate of leak of $A = 0.150$.
Natural rate of leak of $B = 0.096$.

mined and corrected for; besides, the two systems had practically the same capacity, so there is no appreciable error introduced if this correction is not applied.

In proceeding with this arrangement a series of readings shown in Table X were taken. The area of opening of *B* was set at different values and the opening in *A* was varied until the

electrometer needle was balanced. Then the rate of discharge of A should have the same ratio to the rate of discharge of B as the size of the opening of A has to that of B. Thus this ratio should remain a constant as the ionization effect is balanced each time. The results agree with this theory to within one place in 200. They were therefore taken as sufficient evidence that the theory and method are correct and valid.

PLOT VII.



Readings with only one set of quadrants, needle out.

In applying this method to the problems of relative intensities of Röntgen rays it is only necessary to measure the areas, as will be readily seen by applying it to the determination of the coefficient of absorption of metals. From hypothesis 2, the amount of ionization varies directly with the area of opening which permits the ionizing rays to enter the chamber. Also the amount of ionization is directly proportional to the intensity of

the rays. Therefore, in order to get any desired amount of ionization, that is, in order to balance the ionization in B, we

TABLE VIII.

Time in secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.	Ratio of discharge $A \div B$., mean.	Depth of opening in A.
60	92 71	84 63	7	12	0.569	3.0 mm.
60	93 69	86 61	10	16		
60	94 56	86 57	24	20	1.205	6.0 mm.
60	93 50	86 53	29	24		
60	93 23	87 44	60	35	1.724	9.0 mm.
60	92 18	86 41	64	37		
60	94 2	86 40	82	38	2.14	12.0 mm.
60	94 0	86 38	84	40		

Natural rate of leak of $A = 0.23$ divisions per sec. for first four readings.
Natural rate of leak of $B = 0.15$ divisions per sec. for first four readings.
Natural rate of leak of $A = 0.167$ divisions per sec. for last four readings.
Natural rate of leak of $B = 0.133$ divisions per sec. for last four readings.

NOTE.—Connections the same as in Plot VI, excepting that the silk insulated wires that connected the quadrants were replaced by bare wires. Connections do not quite satisfy the ideal conditions yet, as the needle was not steady and the quadrants not at the same potential. However, most of the leak was done away with. The curve is a straight line, but it does not quite pass through the origin. As the conditions approach the ideal, the curve approaches the origin.

must open A an amount that will be inversely proportional to the intensity of the rays entering A. That is,

$$\frac{I_1}{I_0} = \frac{A_0}{A_1} \qquad (1)$$

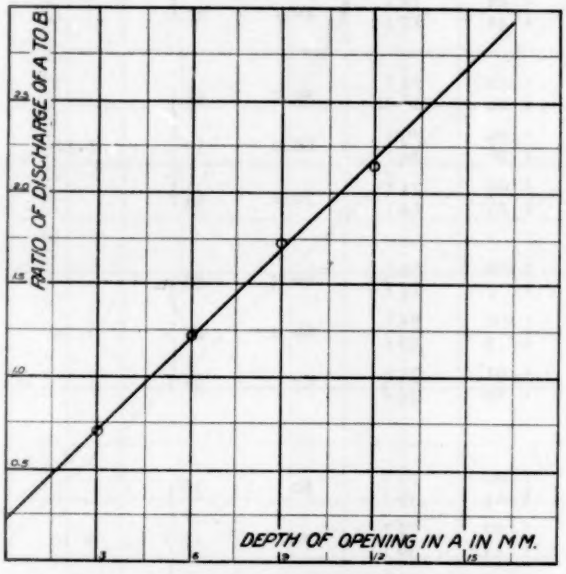
where I_1 and I_0 are the intensities of the rays with and without the absorbing substance in the path, and A_0 and A_1 are the corresponding areas of opening.

The formula for absorption is

$$I_1 = I_0 \varepsilon^{-\lambda x}$$

where λ is the coefficient of absorption and x is the thickness of the absorbing substance.

PLOT VIII.



No needle in *Q E*. Silk insulated wires replaced by bare wires.

Then,

$$\frac{I_1}{I_0} = \varepsilon^{-\lambda x}$$

or substituting the value for $\frac{I_1}{I_0}$ from equation (1) we have,

$$\frac{A_0}{A_1} = \varepsilon^{-\lambda x} \qquad (2)$$

or

$$A_0 = A_1 \varepsilon^{-\lambda x}$$

whence

$$\lambda = \frac{\log_e A_1 - \log_e A_0}{x}$$

TABLE IX.

Time in secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.	Ratio of discharge A. ÷ B., mean.	Depth of opening in A.
60	95 / 52	76 / 24	36.2	47		
60	99 / 54	79 / 25	38.2	49	0.78	3.0 mm.
60	88 / 41	73 / 17	40.2	51		
60	90 / 24	72 / 20	59.2	47		
60	99 / 26	79 / 24	66.2	50	1.32	6.0 mm.
60	90 / 13	74 / 14	70.2	55		
60	100 / 7	79 / 24	86.2	50		
60	100 / 5	81 / 25	88.2	49	1.79	9.0 mm.
40	91 / 19	74 / 34	67	36		
40	99 / 14	78 / 38	80	36		
40	97 / 13	77 / 36	79	37	2.19	12.0 mm.
40	92 / 1	73 / 30	86	39		

Natural rate of leak of $A = 0.113$.
Natural rate of leak of $B = 0.085$.

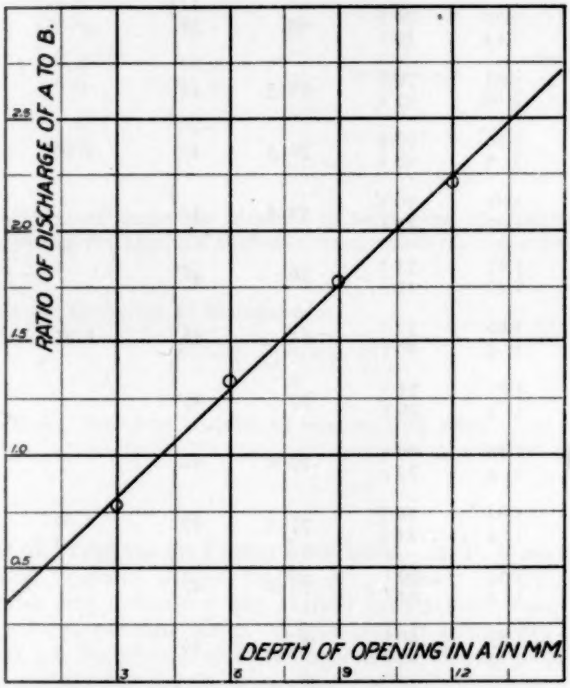
NOTE.—Connections same as in Plot VIII, but needle was anchored so as to keep it at a constant reading. However, the quadrants were not at the same potential and the case was still grounded. In the next Table, No. X, the conditions are made ideal, as when the apparatus is in use for actual measurements.

This method was used to measure the coefficient of absorption of chemically pure tin and the values shown in Table XI are of

the same order of magnitude as those previously obtained by an electroscope method.* The potential, however, in the two cases was different so that no direct comparison can be made.

From the foregoing work the possibilities of this method are easily discernible, its ready adaptability to the various prob-

PLOT IX.



Whole system connected, needle anchored at one position by a Pb anchor in the H_2SO_4.

lems in relative intensity of Röntgen rays, the rapidity with which readings can be taken, the lessening of the chance for personal error, and the high degree of accuracy render it perhaps more desirable than the electroscope method. The difficulties of the scheme have been pointed out as fully as possible in order to aid others in adjusting the apparatus for the use of this method.

* See *Physical Review*, January, 1910.

TABLE X.

Time in secs.	Readings A.	Readings B.	Discharge of A.	Discharge of B.	Ratio of discharge A. ÷ B., mean.	Ratio of area A. ÷ B.
40	85 19	72 34	61	36	1.68	1.65
40	78 19	69 34	65	39		
40	78 14	70 30	65	38		
20	83 10	72 27	71.5	44	1.68	1.71
20	80 8	70 28	70.5	41		
20	81 7	70 27	72.5	42		
8	87 10	73 27	76	46	1.71	1.68
8	86 4	72 26	81	46		
10	82 4	71 26	77	45		
4	82 4	69 22	77.5	47	1.62	1.66
4	82 4	70 21	77.5	49		
4	79 2	69 22	76.5	47		
3	83 3	60 14	80	46	1.71	1.68
3	80 1	60 13	79	47		
3	82 1	60 13	80	47		
2	84 1	58 8	83	50	1.65	1.62
2	85 0	59 7	85	51		
2	85 0	59 5	85	52		

Natural rate of leak = 0.133 for *A* and 0.05 divisions per sec. for *B*. Notice that conditions are ideal and that results are ideal.

TABLE XI.

Reading No.	Depth of opening D_0	Depth of opening D_1	Thickness of tin sheets	Coef. of absorption λ
1	6.5	10.1	0.00126 cm.	343
2	6.6	10.2		
3	6.6	10.15		
4	6.6	14.7	0.00252 cm.	316
5	6.6	14.7		
6	6.6	18.7	0.00379 cm.	275
7	6.6	18.9		
8	6.6	24.0	0.00505 cm.	255
9	6.6	24.2		

The thickness of sheets was obtained by measuring its area, weighing it, and then applying the principle that area times thickness times density equal weight.

Formula for coefficient of absorption is

$$\lambda = \frac{\log_e D_1 - \log_e D_0}{x}.$$

Tin used was found by analysis to be practically pure.

Report of Progress on Flame Standards. E. B. ROSA and E. C. CRITTENDEN. (*Amer. Illum. Engin. Soc. Trans.*, v, 753.)—Treats of the merits and defects of the Hefner amylacetate lamp and the Harcourt 10 c.p. pentane lamp. Eight Hefner lamps are in use at the Bureau of Standards and the conclusion drawn from results with these is that the specifications are not sufficiently precise, and that some lamps slightly depart from the specifications. Of the two styles of light the Krüss alone is recommended. Many determinations of the humidity correction were made, and the result closely agrees with that of Liebenthal, who first determined this correction at the Reichsanstalt. As a standard for comparison they used a carbon filament lamp operated at about 9 watts per candle, which gives a color match with the Hefner. With regard to the pentane lamp a greater difference was found among different pentane lamps than among different Hefner lamps. It is known that this lamp increases in c.p. for some time after lighting, but no careful measurements have been made to show when a stationary value has been reached. The highest c.p. obtained from any pentane lamp tested

at the Bureau is 9.9, while the lamp at the National Physical Laboratory is 10 c.p. The humidity correction is fully discussed, and the barometric pressure correction is stated to be about 0.6 per cent. for a change of 1 cm. in the pressure. It is considered that while the results so far obtained are encouraging, much remains to be done to make the pentane lamp a thoroughly satisfactory flame standard.

The Industrial Fixation of Atmospheric Nitrogen. E. LAMY. (*Met. Chem. Eng.*, ix, 99.)—According to Paul Lemétayer the Chile deposits still contain 240,000,000 tons of nitre, enough for over a century. These deposits cover an area 10,000 square miles. The recent improvements in coke oven practice has raised the total world's production of ammonium sulphate to 800,000 tons per year. Cyanamide when first manufactured was not well suited for agricultural purposes, as it was extremely caustic. This defect has been overcome by moistening and oiling the product before shipment; or the cyanamide powder is mixed with a proportion of iron oxide. The Birkeland and Eyde furnace is remarkably durable, and runs for a year on moderate repair charges; the refractories last 5 or 6 months, and the electrodes 3 to 4 weeks. The two largest of these furnaces have a capacity of 2940 k.w. The Badische Co. furnaces at present use only 700 to 800 k.w.; even then the arc is 22 feet long. The average production from both types of furnaces is nearly equal, about 13,000 pounds of nitric acid per k.w. year. In the Pauling process, at Roche-de-Rame, France, air is blown on a long electric arc. The resulting gas mixture contains 1.15 to 1.20 per cent. of nitrogen oxide at a temperature of 700°–750° C. This excess heat is used to pre-heat the air before it enters the furnace. The final product is sodium nitrate 97–98 per cent. pure. The efficiency of the Pauling furnace is about equal to that of the Birkeland and Eyde or the Badische furnaces. Pauling electrodes last 580 to 600 hours.

Decomposition of Water by Ultra-Violet Light. A. TIAN. (*Comptes rendus*, clii, 1072.)—Very exact observations have shown that under the influence of the radiations emitted from a mercury vapor lamp in quartz, water is decomposed into hydrogen and hydrogen peroxide; and the latter undergoes a further decomposition, yielding oxygen. The quantity of oxygen is however always less than the theoretical amount, but the loss decreases the longer the exposure is continued. This decrease leads to the conclusion that it is due to one of the two following reactions: (1) the inverse action of hydrogen dissolved in oxygenated water, or (2) the combination of hydrogen and oxygen. This latter reaction has been already noted between gaseous bodies at the end of a sufficient period of time the effect of the light is the same as that of electrolysis, with regard to the gases disengaged.

FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, June 21, 1911.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 21, 1911.

President WALTON CLARK *in the Chair.*

The minutes of the previous meeting were read and approved and the report of the Board of Managers transmitted by the Actuary was accepted and ordered filed.

As there was no communication to be presented and no unfinished business the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, June 7, 1911.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 3, 1911.

DR. GEO. A. HOADLEY *in the Chair.*

The following reports were presented for first reading:

No. 2353.—Poulsen's Telegraphone. Advisory. Adopted.

No. 2454.—Thayer's Dirigible Airship. Advisory. Adopted.

No. 2485.—Hixon's Electric Furnace for Smelting Zinc. Advisory. Adopted.

No. 2405.—Law's Universal Clock. Advisory. Adopted.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

Changes of Address.

MR. HIRAM W. HIXON, Worthington, Ontario, Canada.
MR. RALPH D. MERSHON, 65 West Fifty-fourth Street, New York City.
MR. JOS. J. O'BRIEN, Room 18, Provident Bank Bldg., Washington, D. C.
MR. GEORGE R. WOOD, Olive Bldg., Pittsburg, Pa.
MR. WM. A. HAINES, 1712 Green Street, Philadelphia, Pa.

NECROLOGY.

Mr. Edmund Richards Tatham, 1114 Spruce Street, Philadelphia. Born October 4, 1857, son of the late George N. Tatham; died June 19, 1911. He was an alumnus of the University of Pennsylvania and a life member of the Institute.

LIBRARY NOTES.

Purchases.

ROUSSET, J.—Les machines a ecrire.
CHURCH, A. E., AND G. M. BARTLETT.—Elements of Descriptive Geometry.
GARNETT, W. H. S.—Turbines.
American Society for Testing Materials. Memorial volume of Chas. Benjamin Dudley.
PERRIN, J.—Brownian Movement and Molecular Reality.
COLVIN, FRED H.—Machine Shop Mechanics.
ROE, J. W.—Steam Turbines.
KRAUS, E. H., AND W. F. HUNT.—Tables for the Determination of Minerals.
Aeronautical Classics, Nos. 1 to 5 inclusive.

Gifts.

Ontario Department of Agriculture, Forty-first Annual Report of the Entomological Society for 1910. Toronto, 1911. (From the Department.)
Great Britain Labour Department, Fourteenth Abstract of Labour Statistics, 1908–1909. London, 1911. (From the Labour Department.)
Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher, Abhandlungen Band 92–93; Leopoldina, 46 Heft, 1910. Halle, 1910. (From the Academy.)
New York Public Service Commission, Annual Report for 1909, vols. 1 to 3. Albany, 1910. (From the Commission.)
Musee Teyler Archives, ser. 2, vol. 12, part 2. Haarlem, 1911. (From the Museum.)
India Forest Administration, Review of, for 1908–09. Calcutta, 1910. (From the Supt. Government Printing Office.)
Vermont General Assembly, Acts and Resolves passed by the Twenty-first Biennial Session, 1910. Rutland, 1911. (From the State Library.)
Ontario Dairymen's Associations, Reports for 1910. Toronto, 1911. (From the Department of Agriculture.)
Oklahoma Geological Survey, Bulletin No. 2, Report on the Rock Asphalt, Asphalite, Petroleum, and Natural Gas in Oklahoma. Norman, 1911. (From the Survey.)
University of Pennsylvania Engineering Alumni Society. Report of the First Annual Meeting held June 11, 1910. Philadelphia, 1911. (From the Society.)
K. K. Geographische Gesellschaft in Wien, Mitteilungen Band 53, 1910. Wien, 1910. (From the Society.)

City and Guilds of London Institute. Report of the Council, 1911. London, 1911. (From the Institute.)

International Mining Manual, 1911. Denver, n. d. (From Mr. James M. Swank.)

Massachusetts Board of Gas and Electric Light Commissioners, Twenty-sixth Annual Report, 1910. Boston, 1911. (From the Board.)

United States National Museum. Report for the year ending June 30, 1910. Washington, D. C., 1911. (From the Smithsonian Institution.)

BOOK NOTICES.

ELEMENTS OF DESCRIPTIVE GEOMETRY. With applications to Spherical and Isometric Projections, Shades, Shadows and Perspective. By Albert E. Church, LL.D., late Professor of Mathematics in the United States Military Academy, and George M. Bartlett, M.A., Instructor in Descriptive Geometry and Mechanism in the University of Michigan. 286 pages, 8½ x 5½ inches, cloth. Price, $2.25. American Book Company, New York, 1911.

The many friends which this book has made in its long service as a college text-book will be pleased to learn that it will not be suffered to go out of print, although it appears in a much changed form and now bears jointly the names of the original author and the present editor. As formerly published, the text and plates were in separate volumes. The present edition is in a single volume, the beautifully engraved plates having been replaced by well-executed line cuts interspersed in the text.

A few changes have been made in the order of presentation and other features have been introduced to bring it in harmony with present-day methods of teaching. The work, however, retains its former valuable features and in its new form may be expected to enjoy a renewed lease of life.

MEMORIAL VOLUME COMMEMORATIVE OF THE LIFE AND LIFE-WORK OF CHARLES BENJAMIN DUDLEY, PH.D., late president of the International Association for Testing Materials and of the American Society for Testing Materials, 269 pages, portraits, illustrations, 8vo. Philadelphia, American Society for Testing Materials, no date.

This memorial volume contains a series of interesting monographs, covering different phases of the life and career of Dr. Dudley.

The several articles were written by his intimate friends and associates, each selecting one particular topic, the whole illustrating the wide field of activity that came within the range of this many-sided man.

This book is prefaced with a touching poetic tribute from the pen of Dr. Harvey W. Wiley.

The labors of Dr. Dudley were so useful to the Corporation that he served, and incidentally to the whole scientific and industrial world, that the American Society for Testing Materials, whom he had served as President for many years—and who recognized him as their chief source of aid and inspiration—have performed a solemn duty by the preparation of this volume. Those

interested in the life-work, as well as the amiable personality of Dr. Dudley, can procure copies of the book by addressing Prof. Edgar Marburg, Secretary American Society for Testing Materials, University of Penna., Philadelphia.

PUBLICATIONS RECEIVED.

Colorado School of Mines Magazine, vol. 1, Nos. 8, 9, May and June, 1911, 2 parts, illustrations, 8vo. Golden, Colorado.

U. S. Bureau of Mines. Technical paper No. 2. The escape of gas from coal. By Horace C. Porter and F. K. Ovitz. 14 pages, 8vo. Washington, Government Printing Office, 1911.

Automobile Club of America. Technical Committee. Facilities for tests and rules governing tests, together with information regarding the equipment installed in the testing laboratory at the club house. 32 pages, illustrations, 8vo. New York, 1911.

U. S. Department of Agriculture, Forest Service. Circular No. 175. The growth and management of Douglas fir in the Pacific Northwest. By Thornton T. Munger, Forest Assistant. 27 pages, illustrations, 8vo. Washington, Government Printing Office, 1911.

U. S. Coast and Geodetic Survey. Directions for magnetic measurements. By Daniel L. Hazard, computer, Division of Terrestrial Magnetism. 130 pages, illustrations, 8vo. Washington, Government Printing Office, 1911.

Scientific Study of the Criminal. By Arthur MacDonald, Washington, D. C. Reprint from the American Legal News (Detroit, Michigan), for May, 1911. 15 pages, 8vo.

U. S. Bureau of Mines. Technical paper No. 1. The sampling of coal in the mine. By Joseph A. Holmes. 18 pages, illustrations, 8vo. Washington, Government Printing Office, 1911.

North Carolina Geological and Economic Survey. Economic paper No. 21. Proceedings of the third annual drainage convention held at Wilmington, North Carolina, November 22 and 23, 1910, and North Carolina Drainage Law codified. Compiled by Joseph Hyde Pratt. 67 pages, plates, map, 8vo. Raleigh, State Printers, 1911.

U. S. Coast and Geodetic Survey. Results of observations made at the Coast and Geodetic Survey Magnetic Observatory at Sitka, Alaska, 1907 and 1908. By Daniel L. Hazard, Computer, Division of Terrestrial Magnetism. 94 pages, plates, 4to. Washington, Government Printing Office, 1911.

U. S. War Department. Annual Reports, 1910. Containing reports of the Secretary of War, the Chief of Staff, the Adjutant-General, the Inspector-General, the Judge-Advocate-General, the Quartermaster-General, the Commissary-General, the Surgeon-General, the Paymaster-General, the Chief of Ordnance, the Chief Signal Officer, the Chief of Coast Artillery, Chief of Engineers (without appendices), the Departments, the Military Academy, Military Parks, Chief, Bureau of Insular Affairs, Philippine Commission, Acts of the Philippine Legislature, the Governor of Porto Rico. 4 vols., illustrations, plates. Washington, Government Printing Office, 1911.

CURRENT TOPICS.

New Telegraph Cable Between England and Norway. (*Elect. Eng.*, vii, 14.)—A new cable has been laid between Newbiggin in Northumberland, and Arendal in Norway. This is worked by the Great Northern Telegraph Co., for both governments in a circuit from Newcastle to Christiania. The total length is 411 nautical miles. For four nautical miles at the Arendal end the cable is double armored; 66 nautical miles are light deep sea cables, and 341 heavy deep sea cable. The insulation is of gutta-percha.

Sodium Nitrate Substituted for Iceland Spar. ANON. (*Ind. Chim.*, x, 330.)—Crystals of sodium nitrate have been exhibited recently at Paris, so pure and perfectly formed that they can be substituted for calcite in optical instruments. It is expected that these crystals can soon be furnished in such form as to meet all the requirements and thus relieve the instrument makers of the difficulties due to the control of the Iceland spar supply by a monopoly.

Diffusion of Ions in Gases. E. SALLES. (*Comptes rend.*, cli, 712.)—The diffusion coefficients of the positive and negative ions produced in pure oxygen, nitrogen, carbon dioxide, and air by the rays from polonium were measured. In all cases the negative ions move a little faster than the positive, and the diffusion coefficient decreases with the increase of pressure on the gas. The absolute values of the coefficients agree closely with those found by Townsend for these gases, when using other sources of radiation; this shows that ions produced in different ways are identical.

Siamese Bronze. U. S. VICE-CONSUL GENERAL C. C. HANSEN. (*Metal Ind.*, ix, 7.)—Old records state that the art of bronze casting was introduced into Siam by the Chinese in the eleventh century. Bronze figures of Buddha in perfect condition have been found on the sites of ancient temples, when the buildings which formerly inclosed them have long crumbled away. The native name for this bronze is "Samrit." An old formula discovered by Major Gerini gives the proportions 12 ticals (1 tical = ½ oz. av.) pure tin, melt at a low heat, add 2 ticals mercury, stir until amalgamated, and cast into a bar. Take 1 catty (80 ticals) of refined copper and melt it, and gradually incorporate with it the amalgam. Cover the molten metal with ashes of the bŭa-bok (terrestrial lotus), skim off the dross and the metal is samrit bronze. The proportions will be copper 85.11 per cent., tin 12.77 per cent., and mercury 2.12 per cent.

Action of Nitrogen on the Carburization of Steel. J. KIRNER. (*Metallurgie*, viii, 72.)—A mild steel containing 0.1 per cent. of carbon was heated at different temperatures in case-hardening materials containing known quantities of nitrogen. If there was no nitrogen, no carburization occured. Carburization took place rapidly with materials rich in nitrogen at temperatures between 600°C. and 850°C., it was irregular and slower at 900°C., and became rapid again at 950°C. At 600°–850°C. the outer layer of steel contained 0.6 per cent. nitrogen, as the temperature increased the nitrogen decreased until at 1000°C. it was all eliminated. It is stated that a constituent termed "Flavit" was shown when slowly cooled steels were etched with picric acid, which was absent when the steels were quenched, and presumably passed into solution. The percentage of phosphorus, silicon, and manganese remained unaltered during the process.

Tribo-luminescence. W. S. ANDREWS. (*Trans. Amer. Electrochem. Soc.*, xviii, 279.)—A tribo-luminescent product, that is, one that emits light when rubbed or scratched, is prepared by mixing together 70 parts of powdered zinc carbonate and 30 parts flowers of sulphur to a thick cream with distilled water containing a small particle of manganese sulphate. After thorough trituration the mass is dried at a gentle heat, finely powdered, then packed tightly into a porcelain or plumbago crucible with a tight cover and heated to bright redness for 20 minutes. The product emits sparks of a yellowish light when scratched with a knife; the sparks will not ignite inflammable vapor.

Electrolytic Galvanizing. O. HILDEBRAND. (*Elektrochem. Zeits.*, xvii, 304.)—The difficulties met with in electro-galvanizing are caused by (1) the inconvenience of having entirely to surround the article to be treated (as cathode) with the zinc anode, and (2) the poor adherence of the deposited zinc. In the so-called "regenerative method" the anode is of lead and the electrolyte is zinc sulphate, acidified with sulphuric acid. The solution is continuously circulated through the cell and then through a regeneration vat containing zinc dust before it returns to the cell. Rapid neutralization takes place in the vat owing to the good contact with the finely powdered material. In such a cell the zinc deposit is very pure, adherent and uniform.

The Rusting of Iron. ANON. (*Eng. Record*, lxiii, 296.)—The rusting of iron has been investigated by Messrs. Bertram Lambert and J. Campbell Thomson, at Oxford, Eng. They report that perfectly pure iron, water and oxygen remained in contact for months without rusting, while the slightest impurity, even in the absence of all acids, led to rusting and generally with the lapse of only a few hours.

Publications of the United States Geological Survey.—A new list of publications of the United States Geological Survey, just issued, contains the titles of more than one thousand books and pamphlets. These reports cover a wide range of subjects. They include not only papers on geology and topography but reports on water resources and on technology. The Geological Survey was the nursery of the United States Reclamation Service and the Bureau of Mines, which now, in full growth, are carrying along successfully work begun by the Survey years ago. The Survey, however, still continues its work on water resources and includes discussions of technology in its annual volume "Mineral Resources of the United States."

A glance at this list will show the great diversity of the subjects considered and the manifold nature of the science of geology. The reports include discussions of geologic chemistry, mineralogy, petrography, and paleontology, as well as ore deposition and other matters of very practical importance. Much of the Survey's late work has been directed to the study of mineral deposits of economic value. The work done in land classification has not yet found detailed expression in the Survey's reports, but some papers prepared as a result of land classification surveys have been printed annually in bulletins entitled "Contributions to economic geology."

The list may be obtained by applying to the Director of the Survey at Washington, D. C.

Komposite Anti-friction Metal. (*Iron Age*, lxxxvi, 1448.)—The Komposite Metal Co., has established a plant in Philadelphia, for manufacturing high grade metals, making a journal bearing metal its specialty. This metal has extremely high wearing qualities and melts at from 575° to 700° F. according to the grade of metal. This temperature is about 70° F. above the high tin metals. It has a higher bearing strength and is claimed to have better lubricating qualities than babbitt. Komposite metal, as claimed by the company, is not a mechanical mixture but is "a composite metal, scientifically prepared and chemically united, the chemical union of the various metals being thorough and complete," thus preventing them from separating when cooling.

Fermentation of Citric Acid in Milk. A. W. BOSWORTH and M. J. PRUCHA. (*N. Y. Agric. Exper. Stat. Bull.*, xiv, 43.)—During the spontaneous souring of milk the citric acid present as a normal constituent is converted into acetic acid and carbon dioxide. This change is effected by the action of *B. lactis aerogenes*, and not by any of the common dairy bacteria. Two molecules of acetic acid are produced for every molecule of citric acid present. During the process of cheese making, all the citric acid is fermented before the cheese is placed in the press.

Electrical Advance in 1910. (*La Nature,* xxxix, 127.)—The characteristic of the electrical industry in 1910 has been *concentration;* by increasing the active radius of the central stations, and therefore decreasing their number. The conveyance of power depends on the tension of the current, hence in the United States there are cables with a tension of 135,000 volts and in Europe some, the tension of which exceeds 100,000 volts. Ten years ago a distribution of 10,000 volts was considered marvelous and audacious. Electro-motive force has too been largely applied to railroads; with a lively contest between the monophase and triphase currents.

Light.—Great progress has been made in mercury vapor lamps; the lamp with a quartz tube is much more economical than the earlier lamps with glass tubes. M. Claude has invented the ***neon*** lamp, which gives a pleasant reddish light at an expenditure of 0.9 watts per candlepower.

The electrical production of steel and iron has made great advances. Steel made in the electric furnace is characterized by its freedom from scoria and gas; by its great malleability when hot, and by its great resistance to shock. Immense castings are made from it, without blisters or pores.

Wireless telegraphy and wireless telephony have made great progress. In wireless telegraphy the system of sparking has been superseded by systems giving musical notes in telephonic receivers.

Hydrogenite. ANON. (*Rev. Scientifique,* xlix, 81.)—This name is given by Mons. G. Jaubert to a mixture of silicol (a metallic silicide) and soda-lime, which disengages hydrogen gas at a certain temperature. The reaction depends on the decomposition of water by silicium in the presence of alkalies, thus:

$$Si + 4NaOH = SiO_3Na_2 + Na_2O + 2H_2,$$

or with the mixture of soda-lime,

$$Si + Ca(OH)_2 + 2NaOH = SiO_3Na_2 + CaO + 2H_2.$$

Instead of silicium, calcium silicide is used, which is a commercial product sold under various names. Hydrogenite is a gray powder, with an apparent density 1, but, when agglomerated, it attains a density of 2.5. One kilogramme produces from 270 to 370 litres of hydrogen, according to the method used. It is produced to use hydrogenite to replace the leakage of gas from balloons.

Explosive "Dont's." ANON. (*Eng. Record,* lxiii, 225.)—The United States Bureau of Mines has issued a number of rules regarding the precautions to be taken to reduce the risks in storing, thawing, handling and using explosives. These were prepared by Mr. Clarence Hall for the guidance of coal miners, and are well worth the close attention of all miners and others who use explosives.

The World's Production of Metals. ANON. (*Mon. Scient., Mercure,* v, 21.)—There were produced in 1909, 844,100 tons of copper, about 100,000 tons more than the previous year, and the consumption increased from 643,700 tons in 1908 to 728,800 tons in 1909. The United States consumed 318,900 tons in 1909, Germany consumed 179,100 tons, England 109,100 and France 73,100.

Of lead 1,052,500 tons were produced. Europe produced 505,800, the United States 339,700, Mexico 118,000, Australia 77,200. The United States used 365,200 tons, Germany 213,200, England 199,500, France 110,400 and Russia 38,300.

There were produced 108,300 tons of tin; 61,500 came from the Straits and 35,500 from Bolivia. Germany produced 8990 tons from Bolivian ores. The United States consumed 42,800 tons; England 17,500; Germany 17,100; France 8,750 and Belgium 1,300.

The United States produced 240,446 tons of zinc, Germany 220,100 and Belgium 167,100. The total production was 783,200 tons.

From a total product of 16,100 tons of nickel, 9,000 were from the United States; 3,100 from Germany and 2,800 from England.

While the consumption of aluminum has risen to 30,800 tons, the production was only 24,200 tons.

Of the 3,200 tons of mercury produced in 1909, England absorbed 1,445 tons and Germany 723 tons.

Commercial Silicon. ANON. (*Mon. Scient., Mercure,* v, 20.)—Commercial silicon is produced at Niagara Falls, by F. I. Tone's process. The furnace used consists of two electrodes plunged into a mixture of coke and sand. A furnace of 1200 h. p. yields 594 to 792 pounds for every five hours. Three qualities are produced containing 90, 95 and 97 per cent. of silicon. The first is used as a deoxidizer in the purification of steel. It is worth $120 per ton by the car-load.

Sical is an alloy of silicon and calcium formed by the reduction of lime by silicon; it is used in the purification of steel.

Commercial Metallic Uranium. W. P. JORRISSEN AND A. P. H. TRIVELLI. (*Chem. Weekblad.,* viii, 59.)—On exposing commercial metallic uranium to cathode rays a considerable quantity of nitrogen was evolved. It was found that the commercial product contained 13 per cent. of uranium nitride (U_3N_4) and 1.25 per cent. of carbon.

Phosphate Deposits in Montana. *Oil, Paint and Drug Reporter,* Feb. 20, 1911.)—The U. S. Geological Survey reports extensive phosphate deposits in and near the canyon of the Big

Hole River, about 30 miles southwest of Butte. It is probable that similar deposits exist over a large part of western Montana. Sulphuric acid for the conversion of the mineral phosphates into superphosphate could be readily obtained from the waste gases of the numerous smelters in that region.

Electric Arc Welding Processes. C. B. AUEL. (*Amer. Mach.*, xxxiv, 479.)—This article describes fully three processes, with their limitations, the apparatus used, the range of work done, the time required, and the results obtained. It also presents suggestions and cautions for their successful application. Undoubtedly this will repay any person interested for its perusal.

Austrian Electrical Directory.—The Electrotechnical Society of Vienna is about to issue a directory of the electrical power stations in Austria and Bosnia-Herzegovina.

The number of electrical stations in Austria is about 800 and they supply current to more than 1,600 cities and towns. The book, which will bear the title "Statistics of Electrical Plants in Austria," will contain the names of the proprietors of the plants with their addresses, the names of the architects, the places supplied with power and much other information relating to the stations, the dynamos and accumulators, the current, motive power, voltage and area supplied. The number of incandescent and arc lamps, the number of meters and motors with memoranda as to their efficiency, as well as data regarding the price of current, capital invested, annual quantity of current produced, etc., will be included.

The work, which has been compiled with the greatest care, will appear in print about July 1st, and will be issued by the Society. As this book, as well as others issued by this Society, is not a money-making venture but is intended for the use of all who are interested in electrical engineering, the price will be comparatively low, and it may be ordered at this time for 2.80 crowns, post paid. After the appearance of the directory the price will be advanced to 3.80 crowns.

The Lost Art of Tempering Copper. ANON. (*Brass World*, vii, 174.)—The Aztecs, Toltecs and Tarascans, it is said, possessed in prehistoric ages the art of tempering copper. Several archæologists and ethnologists of Mexico City now deny they had such knowledge. Copper axes and knife blades found at Atcapotzalco are so soft they can be cut with an ordinary pocket-knife. On the other hand, Tarascan copper cutting implements from the Balsas River ruins in Guerrero were so hard that they would turn the edge of a modern knife. Analysis showed that these different blades were of the same composition as the copper ores found in the respective localities. The soft blades were made from comparatively pure copper

ores, while the hard, apparently tempered, blades from Guerrero, were made from the natural ores which existed in the hills, alloyed with nickel and cobalt; thus making the smelted metal (or alloy) almost as hard as steel. Hence the so-called tempering was due to the natural alloy found in the ore, which when heated and sharpened gave a hard, cutting edge. On the other hand, where the ores were practically pure copper, the implements made from such ores were soft and remain so to this day.

New Treatment of Aluminum for Soldering. English Patent of L. MAITRE. (*Brass World*, vii, 171.)—Aluminum can be easily soldered if a thin layer of iron is first deposited on the surface. Then plunge into boiling water and then in cold water. Now re-heat until the deposit has acquired a blue color, and again immerse in cold water, like steel is hardened. This treatment causes the iron deposit to adhere more strongly to the aluminum base. The film of blue oxide is now removed from the surface of the iron deposit on the aluminum by fine emery cloth and the soldering proceeded with by any regular method.

Binders for Foundry Cores. H. M. LANE. (*The Iron Age*, lxxxvii, 1140.)—This gives a full account and description of binders and indicates the proper binder for different kind of sands. The results are thus summarized. The action of core binders must be considered from the following points of view: The core must have sufficient strength to stand up before and during drying. This necessitates the use of a green binder for some classes of work. Flour and dextrine and other gluten products are the best green binders, next to these come clay, glutrin and molasses. Oil, rosin, and pitch are of little use as green binders; but the manufacturers of the black compounds frequently introduce dextrine or clay to serve as a green binder. The most efficient final binder in the dry core would be one in which all of the binder would be gathered at the contact points of the sand, so as to leave the vent passages free. Oil, or blends of oil and glutrin or glutrin and clay, seem to fill these requirements fairly well among the liquid binders, and rosin and pitch among the dry binders. But all the dry binders have a greater or less tendency to roughen the surface of the sand in the vent passages and to partly stop the vents. This is largely true on account of the fact that these binders are generally used with loamy sands or in conjunction with flour and dextrine.

Coloring and Oxidized Finishes. ANON. (*The Metal Ind.*, ix, 203.)—In producing oxidized effects upon coffin hardware some consumers prefer the green gray tone. This is produced by using a weak solution of potassium sulphide to which a little ammonia is added and it is used slightly warm. The articles are immersed without scratch-brushing until the green is produced.

Armor Plating and the Simpson Weld. (*Times, Eng. Supple.*, 1911, xxiii.)—It is stated that whilst Krupp armor is estimated to have 50 per cent. more resisting power than Harveyized armor, Simpson armor is to have a resisting power 75 per cent. greater than Harveyized armor. About 3 years ago W. S. Simpson found that when two plates of steel, with a section of copper between them, were placed in a mixture of carbon, brown sugar, and water of the consistency of compressed snow, and the whole mass submitted to a temperature of 2000° F., the copper melted into the steel and formed a perfect weld. So complete was the union between the two plates that, however treated, they would not part nor split at the juncture. Moreover the copper increased the tenacity of the steel. Samples of such welds were submitted to Prof. J. O. Arnold, who examined them by alternating stress tests and micrographic analysis. Referring to one micrograph he said that it showed "a portion of the thin weld line, in which a considerable part of the copper seam has disappeared owing to the metal dissolving in the steel to form a solid solution micrographically almost indistinguishable from the steel itself. Had the welding been continued for some time longer there would be no visible weld line left, but merely a solution of the copper in the steel, molecularly continuous with the steel itself and considerably stronger than the main body of the metal, because the copper will have disappeared (visually) after having brought into perfect continuity the molecules of both faces of the steel."

Application to Armor Plating.—As is well known, by the face-hardening processes which have been in use for some time past, carbonization of the armor plate does not extend deeper than 7/8 of an inch. A hard face and a tough back are obtained, but the hard face is neither as hard nor as thick as could be wished. If, then, it were possible to take high speed steel, say of double this thickness, and weld it to a soft steel backing, an immense advantage would be gained, and that is what the Simpson weld can do. Not only is the high-speed steel many times harder than ordinary steel, but the hardened face of the plate can be made of any desired thickness. It is understood that trials have been made already with plates of the usual regulation size in which 2 inches of hard steel were welded to 4 inches of soft, and which gave entirely satisfactory results when attacked by a 6-inch gun.

"Coslettizing" or Rust Proofing of Iron and Steel. EMMANUEL BLASSETT, JR. (*The Metal Ind.*, ix, 207.)—This finish is a dilute solution (about 4 per cent.) of phosphoric acid mixed with iron filings, kept at boiling temperature. The process is very simple and always produces good results. The metal to be treated is first immersed for a few seconds in a boiling solution of potassium or sodium hydroxide (caustic) and if rusty or greatly tarnished is put through the regular sulphuric acid pickling solution. It is then

rinsed in water and placed in the "Coslettizing" solution, kept at the boiling point for 2½ to 3 hours. When completed the metal has a greenish-black appearance. It is dried, then oiled with linseed or paraffin oil, which gives it a gray-black color.

Spontaneous Combustion of Coal. A. W. PARR and F. W. KRESSMAN. (*J. Ind. Eng. Chem.*, iii, 151.)—Oxidation processes begin in freshly mined coal at ordinary temperatures, and they are of different character and vary in their speed and intensity. In general each kind of coal has a critical temperature of oxidation, below which the process, resulting from external factors, does not prove ultimately destructive and stops when the exciting causes are removed; but above this temperature the oxidation becomes autogenous and results in the ultimate destruction of the coal. Autoxidation begins at 200° to 275° C., according to the fineness of division of the coal, while ignition does not occur under 550° C. The temperature of autogenous oxidation depends upon a number of factors, which include: (*a*) external sources of heat, (*b*) fineness of division, (*c*) easily oxidizable compounds, (*d*) iron pyrites, (*e*) moisture, (*f*) oxidation of carbon and hydrogen. Autogenous oxidation begins at 200° C., to 275° C., while above 300° C. an exothermic decomposition begins and raises the temperature until ignition occurs usually at 350° to 400° C.

Separation of Metals from Complex Ores. H. L. SULMAN and H. F. K. PICARD. (*Eng. Pat.* 8650, 1910.)—This process is applicable to any mixture where one of the metals is more easily reducible than the other. A mixture containing the oxides of zinc and lead is crushed and heated with carbon, or in an atmosphere of reducing gas, to a temperature of about 600° C., when the lead alone is reduced to metal, distributed in small particles through the mass. The product is cooled, under conditions preventing re-oxidation and then concentrated by vanning or flotation, to separate the lead particles; the zinc and silica being left in the watery pulp. Sulphide ores must first be calcined; should any sulphide of the more easily reducible metal be oxidized to sulphate, it will be again reduced in the final reduction and can be easily separated.

Sterilization of Water by the Quartz Lamp. (*Eng. Record*, lxiii, 485.)—Considering the great interest in the sterilization of drinking water by various means, it is surprising that so little has been done with the quartz-mercury lamp in this country. The foreign reports indicate so great bactericidal power in the radiation from the quartz lamp as to make it worthy of careful study as a practical means of sterilization. The effective rays are those of extremely short wave-lengths, so short that they are wholly stopped by glass and do not escape from the glass tube usually used in mer-

cury lamps. These short radiations, having a wave-length of approximately 0.00001 inches, get through the quartz lamp and are still very powerful at a distance of 1 or 2 feet, though they are readily absorbed by air. Cernovedeanu and Henri made some experiments, which give very striking data as to their rapidly destructive action on bacteria, when the water is within a short distance of the tube, 15 to 20 seconds exposure completely destroyed *B. coli* and many other forms of bacterial life. The water is led in a circuitous channel so that it passes repeatedly within the effective radius of action of the quartz lamp, and produces very complete sterilization. Its only effect on the water is to produce very slight traces of hydrogen peroxide. The energy required for the lamp is an ordinary continuous current at 110 or 220 volts; this requires no special apparatus and no attention. This simple and effective process will, it is to be hoped, be thoroughly tried out in this country so that its field of usefulness will become clearly known.

Cupror, a New Alloy. ANON. (*The Metal Industry*, ix, 95.)—Cupror is a newly discovered alloy of copper and aluminum, of gold-like appearance. Its tensile strength is 93,000 lbs. to the square inch. Its gold-like appearance and lustre are unchanged by atmospheric conditions. It has remarkable toughness and ductility, and can be drawn, spun and handled in every conceivable way with facility. Its close resemblance to 18-carat gold deceives even jewellers. It is valuable for the manufacture of brass bedsteads, automobile fittings, ship fittings, building hardware, railroad car fittings, chandeliers, etc.

Chinese Jewelry Made in Germany. U. S. Consul J. C. MCNALLY, Tsingtan, China.—Germans are now producing imitation Chinese jewelry embossed with Chinese characters signifying "longevity" and "good-luck," heretofore exclusively manufactured by the leading Chinese firms of Canton and Hongkong; such as cuff links, watch fobs, cravat pins, brooches and so forth. The German goods are of superior workmanship, but the grade of gold is only 14 carat, while the Chinese grade runs from 18 to 24 carat. Moreover, the Germans have produced an artificial jade stone, so close to the real Chinese jade that dealers themselves can be deceived. The Chinese houses are about to substitute the imitations in their mountings, and when travellers in the Orient purchase jade ornaments, they should bear these German imitations in mind.

Pickling Aluminum. ANON. (*The Metal Industry*, ix, 79.)—To free aluminum from grease, oxide or other foreign substances, and to give it a good surface, the German Aluminum Industry Co. uses a hot 10 per cent. solution of sodium bicarbonate, saturated with common salt. The articles are dipped therein for 15 to 20 sec-

onds, taken out and brushed; dipped again for half a minute, well washed with water and finally dried in saw-dust. This gives them a color like matted silver. If only a good polished surface is desired it is enough to dip them in a dilute solution of caustic potash, then rinse and dry thoroughly.

Smoke Prevention in England. U. S. Consul CHAS. N. DANIELS, Sheffield. (*The Metal Industry*, ix, 79.)—A smoke consumer and fuel economizer was successfully demonstrated in Rotherham, before the members and officials of the corporation. It is said to be the result of 20 years' experimentation. Coal was fed to the furnace of a boiler with the usual result, the emission of black smoke from the stack; then the consumer was put in operation and, at once, the black smoke disappeared, and there was only a trace of the products of combustion.

The effect is produced by a series of devices so placed in the flues as to intercept the smoke and cause it to be ignited by the flame. Two air circulators are so placed as to allow the desired quantity of external air to be circulated among these devices, causing the smoke to be properly ignited and consumed, before reaching the chimney. There is nothing to get out of order and a saving of fuel is claimed. The apparatus can be affixed to almost any type of boiler during a week end.

Handling Iron Ore With Electric Magnets. ANON. (*Iron Age*, lxxxvii, 431.)—The *Electrical World* states that at Moose Mountain Mine in Ontario, Canada, high-grade magnetic iron ore is picked from the ground and loaded into cars by electro-magnets. The ferrous material found on the side of a hill is loosened and broken down by blasting, and rolls to the foot of the hill, where an electro-magnet, mounted on a crane, picks it up and loads it into mine cars, at the same time making a rough separation, since rock and non-magnetic material are left behind. The electro-magnet can handle 1200 lbs. of pig-iron at a load, but the magnetic quality of the unrefined ore is such that 800 lbs. can be picked up easily. This is the average of a number of loads the individual lift sometimes being several hundred pounds greater. A steam shovel was formerly used for loading the ore, but the density and hardness of the magnetite destroyed the buckets rapidly. The electro-magnets also save handling a quantity of stone, and thus relieve the crushing and magnetic separating plant, where the material is concentrated before being shipped.

Tinning Articles of Gray Iron, Malleable Iron and Steel. C. H. PROCTOR. (*The Metal Industry*, ix, 68.)—Although electro-galvanizing has greatly advanced in the last decade, and the zinc protects the iron from rusting, yet galvanizing will never replace tin for culinary and other household articles; for tin is the more attrac-

tive metal and not poisonous as is zinc. Electro-tinning does not seem likely to replace molten or dip tinning. The process of hot tinning may be summarized as follows:

I. Cleansing from sand or scale by pickling in hydrofluoric acid, at 5° to 10° Beaumé.

II. Tumbling in an ordinary tumbling barrel, using sal soda and water as the medium, for thirty minutes to one hour.

III. Washing in cold water and immersing in a 5 to 10 per cent. solution of hydrochloric acid to remove oxidation. Then immerse in a flux of concentrated zinc chloride. Four to five pounds of sal-ammoniac (ammonium chloride) is added to each gallon of the acid.

IV. Drain the articles well and immerse in the molten tin pot, where they remain until they get sufficiently hot and are thoroughly coated with tin. Remove from the bath and throw off the excess of tin by a quick motion. This is the first coating. The bath should be at 500° F.

V. Quickly immerse in the second or finishing bath, at a temperature of 400° F. The surface should be covered with a mixture of five pounds beef tallow with one pound of palm oil, to a depth of from one-half to two inches. This acts as a flux, makes the tin run freely, prevents oxidation and gives a more uniform coating. The excess of tin is removed by slinging motions, and then the article is immersed in kerosene oil, kept as cold as possible by a jacket of cold water, to keep down the temperature and prevent ignition.

VI. Now plunge the articles in clean, boiling water to remove as much kerosene as possible, and dry with cheap wheat flour or fine maple sawdust. Sometimes three or four tinning kettles are used, each at a lower temperature, when a heavier coating is required.

Straits of Banca tin should be used for good results. The process can be cheapened by adding from 25 to 50 per cent. of lead. Small articles are tumbled dry to polish the surface.

The Displacement of the Zero Point in Balances of Great Precision. M. MANLEY. (*Rev. Scientifique*, xlix, 500.)—Small irregularities are frequently noticeable in very delicate balances. These are troublesome in operations requiring very exact weighing; such as the determination of atomic weights, measuring the density of the earth, standardizing weights, etc. The reason of this displacement has been studied theoretically and experimentally. The change in the position of equilibrium of a balance is due to the following four causes: (1) Lateral slipping of the central knife-edge on its support; (2) variable and continuous flexion of the beam after loading the pans; (3) lateral displacement of one or several knife-edges; (4) small differences in temperature between the two arms of the beam. The two first causes have no appreciable practical effect; the two last are the actual causes. With regard to the temperature it has been shown by means of a very sensitive differ-

ential bolometer that there is a slight but rapid and almost continuous variation in temperature of the air immediately surrounding the beam. Further, when the pans have just been loaded the changes of temperature of the two arms of the beam are markedly increased; so that it is necessary for taking an exact weight to wait 10 or 15 minutes before taking the final reading. It is also necessary to "fatigue" the beam by letting it oscillate freely for a certain time after loading the pans. The quantity which expresses the displacement of the zero point of a very precise balance is a very regular function of the temperature of the beam. These irregularities can be overcome to a great extent by using a small cover around the beam of the balance, to protect it from external heat and convection currents.

Copper Poisoning. C. A. HANSEN. (*Gen. Elect. Research Laby, Met. Chem. Eng.*, ix, 67.)—This is a warning to those working with copper in an electric arc furnace of the poisonous effect of copper fumes. Ten men, all old hands in smelting work, were melting 5000 pounds of pure electrolytic copper scrap in a 3-phase arc furnace. The run occupied 5 hours, and 3 hours after pouring off they suffered great inconvenience in respiration, and for 24 hours severe nausea and soreness were experienced, similar to an attack of acute grippe. The run was made under the most favorable conditions as to ventilation, so that if the ventilation had been poor the results would probably have been very serious.

The Action of Ultra-Violet Rays on Rubber. V. HENRY. (*Caoutchouc Guttapercha*, vii, 4371.)—The action of the ultra-violet rays on raw para, plantation rubber and the rubber obtained by the evaporation of *Hevea latex* was investigated. The last was attacked by the light, entirely losing its elasticity and becoming sticky. The plantation rubber was not attacked so greatly, the Para least of all. Vulcanization greatly increases the resistance to the rays, as does the addition of mineral matter. The action of the rays is really an oxidation, since the rubber is not attacked if exposed to the rays in evacuated quartz tubes. The rays with the largest coefficient of refraction are the most active. As the higher atmospheric regions are rich in ultra-violet rays, these experiments are of practical value on choosing rubber coverings for balloons.

Specifications for the Quality of Gas. H. BUNTE and H. STRACHE. (*J. Gasbel*, lii, 817.)—With the extensive use of gas for heating and lighting purposes, the candlepower standard of measuring the quality of gas is both inadequate and misleading. Candlepower measures only the light producing power of gas when burned in an open flame; it tells nothing about its value for heating purposes. The researches of St. Clair Deville in 1903, and the more recent ones of Bunte and his assistants, have shown the remarkable fact, that within certain limits and certain well defined conditions the light-

giving power of gas is proportional to its heat value; or with the same gas, the light emitting power of the incandescent mantle is proportional to the number of heat units fed to the burner per unit of time. This is not an exact law, but a serviceable rule. The true value of gas, then, both for light and heat can be measured by its calorific power, this is the only logical measure. A gas having a calorific value of 5,200 cal. per cubic metre is recommended as the standard. The latest designs of burners for heating and lighting require that the gas should have an approximately constant composition, since the maximum efficiency of the burner is only obtained when the relative amounts of air and gas are closely regulated. Water gas may be added to prevent excessive variations in calorific value. Gas should be free from hydrogen sulphide, cyanogen, and ammonia. The gas producer should choose that coal which on distillation yields the greatest part of its heat value in a gaseous form.

Installations of Girod Electric Furnaces. (*Elec. Rev.*, lviii, 300.)—Six Girod furnaces are at work at Ugine, France, on cold charges. Two with four electrodes refine 18 tons of cold scrap or 20 tons of molten scrap, with a power of 1200 to 1500 k.w. Two others with a single electrode, at 325 to 350 k.w., have a capacity of 3 tons cold and 4 tons hot. Two furnaces of 2 tons capacity are also in use, and a new 8000 k.w. power furnace is being installed. The product is high-grade tool steel, projectile steel and steel for castings, auto-frames, etc. The Girod Co. has 40 furnaces operating on ferro alloys. The Cockerill Co., Belgium, and Krupp & Co., Germany, and the Simonds Mfg. Co., Chicago, are all using Girod furnaces to produce high-grade steel.

The Effect of Copper on Nickel-Plating Solutions. (*Brass World*, vii, 45.)—Experiments to ascertain the effects of copper on nickel-plating solutions, gave the following results: (1) The pressure in a nickel-plating solution of as small an amount of copper as 1/64 oz. to the gallon is appreciable and slightly darkens the nickel deposit. This is about 1 per cent. of the quantity of nickel present. (2) When the quantity of copper is increased the nickel deposit becomes still darker and a smut forms. Therefore, the presence of copper must be regarded as an injurious ingredient in a nickel-plating solution.

Production of Tungsten Wire for Lamp Filaments. (*Elect. Rev. and West. Electrician*, lvii, 790.)—Particles of metallic tungsten are first heated in a practically closed crucible and phosphorus introduced from time to time in small quantities, but sufficient to convert all the tungsten to tungsten phosphide. In this way relatively small amounts of tungsten phosphide are produced, but as it is fusible a large number of these particles are put into the crucible and fused into a single ingot. This phosphide ingot is then made the cathode

in an electrolytic bath to reconvert it to metallic tungsten. This renders it more or less porous. To make it compact it is subjected to a white heat under an oxy-hydrogen blowpipe while being simultaneously worked by hammering and rolling. The heat must not be high enough to cause oxidation. The ingot is cooled and the process repeated to make it more homogeneous and ductile. When the requisite tenacity is attained the ingot is hammered and compressed to a long drawn-out rod. This is cooled and again heated, but to a lower temperature, and drawn out to a wire by passing it through suitable dies. This wire is claimed to be so ductile and flexible that it can be formed into any shape of filament.

Application of the Thermopile to Photometry. J. G. FELTON and E. J. BRADY. (*Amer. Ill. Eng. Soc. Trans.*, v, 729.)—A description of the application of the thermopile to determine polar curves of a large number of illuminants, comparing the curve obtained photometrically with that of the thermopile. In glow lamps the agreement was good, but incandescent gas lamps, which generate heat, give abnormalities. The results are also complicated by glass reflectors, some of which are much more transparent to light than to heat.

Atherium; a New Alloy. (*Electrician*, lxvi, 525.)—This is a new, white metal alloy, lighter than aluminum, its specific gravity is 2.4 to 2.57. A test-piece 0.628 inches in diameter gave an elastic limit of 33,712 pounds per square inch, an ultimate strength of 41,798 pounds per square inch, an extension of 17.5 per cent. on 2 inches, and a reduction of area of 39.1 per cent. This alloy gives sound castings, rolls and turns well, and can be soldered, forged and welded. It is claimed that it does not tarnish nor corrode and withstands the action of sea water.

Advantages of Unified Electric Systems Covering Large Territories. W. B. JACKSON. (*Amer. Inst. Elect. Eng. Proc.*, xxx, 173.)—These advantages are mentioned: (1) Saving in power-house equipment through taking advantage of the diversity of different communities by serving them from the same transmission system. (2) Lower cost of power generating per k.w. hour, due to larger power plants and improved load factor. (3) Smaller investment in power plants per k.w. capacity in larger plants as compared with smaller. (4) The possibility of decreased percentage of spare apparatus by appropriate arrangement of power plants. (5) Saving in cost by centralized management, general superintendence, and other general expenses. (6) Possibility of providing rural and suburban service that could not be profitably done by a local central station. (7) The possibility of large corporations providing power service that would be too expensive for small companies. (8) The development of water power for electric service.

Micrographic Examination of Cast-Iron in the "Graphitized" Condition. O. KRÖHNKE. (*Metallurgie,* vii, 674.)—A peculiar decomposition of cast-iron tubes converts them into a soft dull gray or dark brown mass, somewhat similar to graphite, while they retain their external shape. There are various methods of causing this change, and the converted material has a specific gravity of approximately 2, and can be cut with a knife. Tubes of various compositions have been buried in the earth and then, at different degrees of conversion, examined micrographically. One specimen with a normal composition: total carbon 3.81 per cent., graphite 2.96, sulphur 0.097, manganese 0.55, silicon 2.33, phosphorus 1.850, iron 91.82 per cent., was converted to this composition—total C, 9.85 per cent., graphite 8.83, S 0.518, Mn 1.10, Si 4.25, P 3.60, Fe 68.6 per cent. Apparently the changes are: (1) Pearlite disappears, but only the ferrite is dissolved from it; (2) the graphite remains, but is converted into a peculiar grayish-white or white modification according to the extent of the conversion (Graphitierung); (3) cementite and the phosphide eutectic remain unchanged. White iron containing no graphite, and wrought iron tubes, do not appear to undergo the change. It seems, therefore, that the destruction of the tubes is caused by electrolytic action set up between the graphite and the other constituents of gray iron.

Planck's Formula for Diffusion Potentials. N. BJERRUM. (*Zeit. Elektrochem.*, xvii, 58.)—It is shown that in certain cases Planck's formula is not reliable and Henderson's formula is preferable. An experimental arrangement is given where Planck's formula is valid.

Observations of Humidity on Mars. J. HANN. (*Meteorogical Zeitschr.*, xxvii, 522.)—An expedition was made from the Lick Observatory to the summit of Mt. Whitney to endeavor to determine amount of water vapor present in the atmosphere of Mars. The results depended on the degree of exactness with which the humidity of the earth's atmosphere could be determined. Then by comparative spectra of the Moon and Mars at about equal altitudes, the intensity of the "*a*" water-vapor red band was measured. The conclusion arrived at was that there was little evidence of the presence of more water-vapor on Mars than on the Moon.

PRESS OF
J. B. LIPPINCOTT COMPANY
PHILADELPHIA